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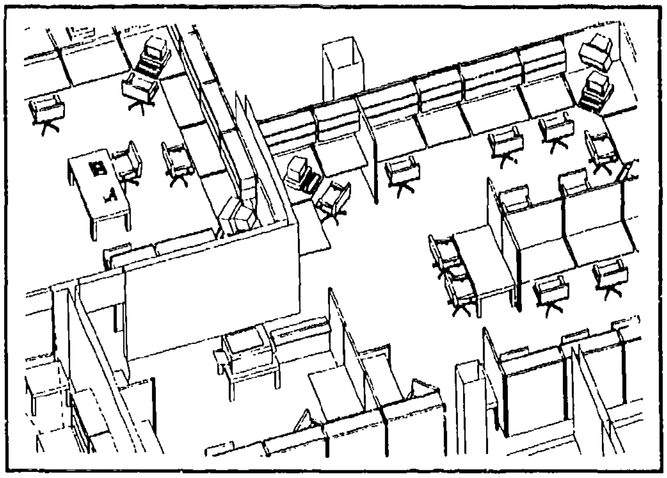
The Value of Interior Design

A Description of the Benefits of Applying Interior Design Principles to U.S. Army Facilities

by
Douglas C. Heinen
Simone N. Demirjian
Todd A. Pardon
Blessing F. Adeoye
James R. Anderson
Susan Weidemann



The effectiveness of U.S. Army personnel depends heavily on the design of the facilities they work in. Interior aspects such as floor layout and workstation configuration can affect worker productivity, comfort, safety, and health. Inadequately designed facilities can decrease worker productivity and increase life-cycle and medical costs, impairing the Army's ability to fulfill its mission.

The interior designer coordinates a facility's design needs to create a facility that supports the group's mission and enhances worker productivity and job satisfaction. Applying proper interior design principles early in facility design can ensure that a building will serve its occupants well and achieve optimal life-cycle costs. Despite the importance of design in facility construction, the Army has often excluded the interior designer from its facility design process.

This research identified and documented the importance of interior design in the construction and renovation of Army facilities, and its implications for facility management activities and the occupants' quality of life. The importance of design principle was evaluated by surveying occupants of the Humphreys Engineer Center Support Activity (HECSA), at Fort Belvoir, VA regarding job-related activities, and the occupants' needs and opinions about the facility before and after the facility's renovation.

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Douglas C. Heinen, Simone N. Demirjian, Todd A. Pardon, Blessing F. Adeoye, James R. Anderson, and Susan Weidemann

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13. ABSTRACT (Maximum 200 words)

The effectiveness of U.S. Army personnel depends heavily on the design of the facilities they work in. Interior aspects such as floor layout, workstation configuration, etc. can affect worker productivity, comfort, safety, and health. Inadequately designed facilities can decrease worker productivity, and increase life-cycle and medical costs, impairing the Army's ability to fulfill its mission.

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This research identified and documented the importance of interior design in the construction and renovation of Army facilities, and its implications for facility management activities and the occupants' quality of life. The importance of design principle was evaluated by surveying occupants of the Humphreys Engineer Center Support Activity (HECSA), at Fort Belvoir, VA regarding its job-related activities, needs, and opinions about the facility before and after the facility's renovation.

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Executive Summary

This report shows the importance of interior design and facility management in creating workplaces that serve their occupants and achieve optimal life-cycle costs, and best support organizational goals.

To understand how equipment, furniture, and spaces (those characteristics of the workplace directly manipulated by interior designers and facilities managers) affect important workplace outcomes such as productivity and job satisfaction, several important components must first be defined. Figure ES1 shows these different aspects.

Those characteristics on the left side of the figure represent objective, measurable aspects of three major components of the work setting: the physical environment (facility), the organizational structure, and the individual worker. However, the people who are associated with that work setting always subjectively perceive these objective characteristics. Based on their perceptions and on actual objective aspects, individual experiences come together in a set of intermediate outcomes experienced by workers that can manifest themselves as either physical or

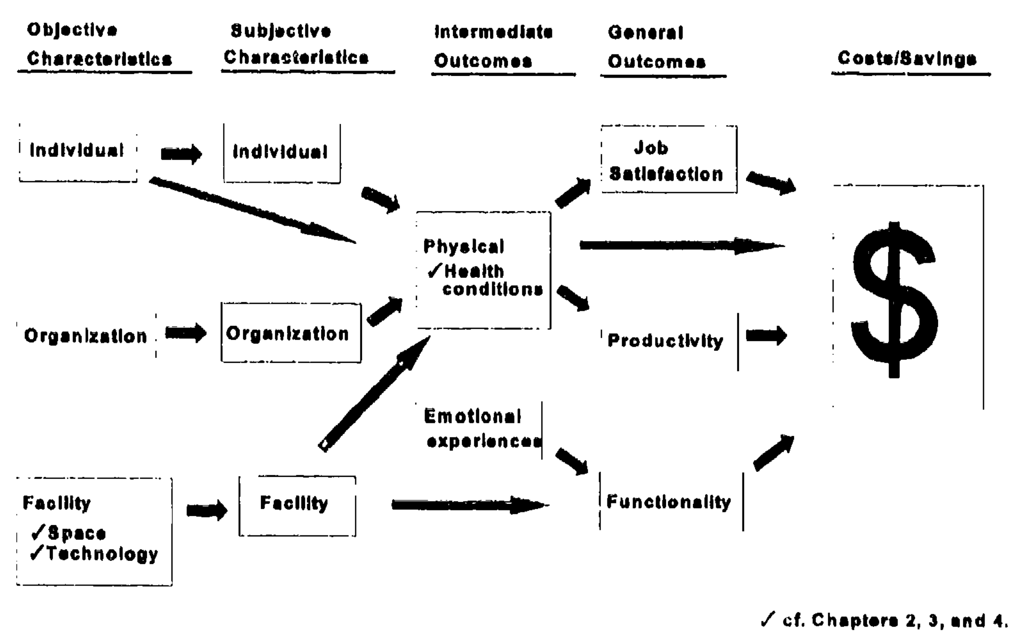

Figure ES1. Relationships between workplace components.

emotional experiences. Finally, there are general outcomes with which most organizations are concerned: functional requirements, job satisfaction, and productivity, all of which impact the cost or savings of a workplace.

Figure ES1 shows how many important aspects of the workplace directly affect the user. By being aware of this entire system, the interior designer can plan for and consider these issues by providing a variety of services and knowledge to any project. This report addresses some of these concerns and provides insights into the value of interior design. It emphasizes the characteristics of the physical workplace, subjective evaluations of those characteristics, and the impact of both these components on intermediate and general outcomes.

Individual Organization and Facility Attributes

Individual organization and facility attributes were researched extensively and documented in various scholarly and scientific publications. Organizational and industrial psychology are two examples of disciplines an interior designer must consider to complete a successful design. Basically, objective organizational attributes include such aspects as organizational structure, management style, as well as subjective perceptions of the organization, e.g., whether the organization is perceived as caring about the workers. Other objective attributes within the organization relate to personnel data, e.g., the age, gender, or level of skill of the workers. Subjective attributes are the individual's perceptions about themselves and others, e.g., "My co-workers are lazy," or "I am capable of doing the job." Workers also have unique personality characteristics that affect their emotional experiences at the workplace, e.g., an optimistic person may express an optimistic attitude about the workplace. Even though these attributes were not emphasized in this study, their assessment is part of the design programming process of a work environment and is therefore addressed in the final chapter. Facility attributes simply relate to the built environment and issues (or perceptions) related to that environment.

Objective Workplace Characteristics

Objective characteristics of the physical work space are those features directly manipulated or influenced by interior designers and facility managers. These include such features as amount of storage space, light and noise levels, type of office equipment, height of shelves, temperature and humidity, capability to meet with people, spatial configuration, and so on. The interior designer is also responsible for the level of quality for the many specified products.

Subjective Workplace Characteristics

Subjective characteristics arise from the perceptions of the people designing or occupying those spaces. They include product performance characteristics and evaluations of the workspace, such as chair comfort, noise level, adequacy of storage space, functional adequacy of space and equipment, or amount of privacy.

Intermediate Outcomes

Intermediate outcomes of most concern within this document involve the worker's physical and emotional experiences that are influenced by workplace characteristics. The physical conditions of muscle pain, repetitive strain injury, headaches, or dizziness are considered, as are emotional experiences, such as feeling excited about going to work, or experiences of stress or boredom. Emotional experiences are discussed in two ways: in terms of the workplace characteristics that might influence or cause them, and how they might influence the more general outcomes of performance and job satisfaction, and in terms of the functional requirements of space. The Appendix to this report includes empirical results from a case study that examined some of these relationships.

General Outcomes

Outcomes of most concern to organizations are: How productive the workers are; whether they have a high level of job satisfaction; and whether the space meets the functional requirements of the task. While these areas have received a great deal of research, much of the empirical work has examined only the link between the organization and the individual characteristics. This report examines a much less-studied linkage—that relationship between the physical environment of the workplace and general facility user outcomes such as performance, and also how the built environment is mediated by subjective perceptions and intermediate outcomes, such as health-related issues. A close look at this interplay of aspects of the workplace demonstrates the importance of the interior designer and facility manager as professionals whose task is to know and smoothly integrate diverse information to improve work environments.

Foreword

This study was conducted for the Directorate of Military Programs, Headquarters, U.S. Army Corps of Engineers under Project 4A162784AT41, "Military Facilities Engineering Technology"; Work Unit FF-AF3, "Model for Configuring Effective Workplaces." The technical monitor was Frank Norcross, CEMP-EA.

The work was performed by the Facility Management Division (FF), Infrastructure Laboratory (FL), U.S. Army Construction Engineering Research Laboratories (USACERL). Alan Moore is Chief, CECER-FF and Dr. Michael J. O'Connor is Chief, CECER-FL. The USACERL technical editor was William J. Wolfe, Information Management Office.

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1 Introduction

Background

The U.S. Army has a unique peacekeeping mission that extends throughout the world. The effectiveness of the personnel who carry out this mission can be heavily impacted by the design of the facilities they work in. Interior aspects such as floor layout and workstation configuration—even the selection of furniture and construction materials—can affect worker productivity, comfort, safety, and health. Inadequately designed facilities—whether work environments or housing—can lead to poor worker productivity, needless life-cycle costs, and large medical expenses. In other words, poor interior design can interfere with the Army's ability to fulfill its mission.

Application of proper interior design principles at the earliest stages of workplace facility design can ensure that a building will serve its occupants well and achieve optimal life-cycle costs. The professional who implements these principles is the interior designer. The starting point for the interior designer's work is complete familiarity with an organization's mission and goals. Each work unit on an Army installation has a specific job to do, and the unit's facility housing must meet certain operational requirements. Designers help translate those operational requirements into an optimal working environment. They coordinate the facility's organizational requirements, mechanical needs, power demands, telecommunications needs, equipment challenges, spatial and ergonomic requirements, privacy issues, acoustical needs, and other design essentials. The designer's goal is to create a facility that supports the work group's mission and enhances worker productivity and job satisfaction.

Advances in technology (e.g., wire management, computers, facsimile machines) have made proper interior design more technically demanding than ever. The Army's growing reliance on the knowledge worker—a person whose main work inputs and outputs are knowledge rather than materials—has further complicated the interior designer's task.

The interior designer's specific tasks include:

- assembling or participating on a multidisciplinary team of experts to fully develop users' functional requirements
- consulting with building occupants on interior design principles to help them more effectively fulfill their mission
- analyzing space adjacencies and organizational requirements
- executing design and construction documents
- establishing product criteria and needs
- coordinating disciplines, trades, and move-in to facilitate a success.

Very often the Army's approach to facility design has not included the interior designer, who has frequently been thought of as an "interior decorator"—someone who coordinates colors, selects carpet and furniture fabrics, and decides where to put the plants. This misunderstanding can prevent the Army from exploiting important facility-design expertise; it is essentially a misunderstanding of the value of interior design and ultimately, of the real cost savings that a well-designed facility can accrue. The U.S. Army Construction Engineering Research Laboratories (USACERL) was tasked to investigate the relationship between workplace interior design and worker effectiveness.

Objective

The objective of this research was to identify and document the importance of interior design in the construction and renovation of Army facilities and discuss the implications of interior design for facility management activities and the occupants' quality of life.

Approach

A literature search was conducted to document interior design principles, technologies, and facility management concerns addressing the needs of Federal interior design professionals. Two meetings were held with tri-service representatives to discuss the problems associated with interim design and poor facilities. The authors investigated problem areas pertinent to interior design and suggested solutions based on the literature, experience, and design theory. Hypothetical problem/solution scenarios are presented. To test and document the principles discussed, the authors identified an Army facility scheduled for renovation—the Humphreys Engineer Center Support Activity (HECSA), at Fort Belvoir, VA—and surveyed one work group about its job-related activities, needs, and opinions about

the facility. After renovation, the work group was surveyed again. The findings of this case study are documented in the Appendix to this report and will be more fully addressed in a forthcoming technical report (Anderson et al. 1994).

Mode of Technology Transfer

The results of this research will be incorporated into the Proponent Sponsored Engineer Corps Training (PROSPECT) courses Interior Design I and Interior Design II. It is also recommended that a concise version of this information be included in a briefing packet for installation commanders and others directly involved in the facility construction and renovation decisionmaking process.

2 Space Planning Issues

Money is one of the most obvious measures of the value of a decision. With budgets becoming tighter throughout both the government and private sectors, facility planners and managers are focusing on controlling extraneous expenses and making decisions that maximize the return on investment of facility dollars. As a result, the perception of the built environment has changed from being considered a necessary overhead to a cost that can be manipulated and managed to increase cost-effectiveness (or, in the private sector, profits).

This new understanding of the built environment has significantly altered the role of interior design. Interior designers have been inaccurately perceived as interior decorators—whose concern is with matters of appearance alone, and who do not address the issue of functionality. Designers evaluate products and plans for health and life-safety issues, and also to eliminate unneeded expense, provide cost-justification data, manage inventories and properties, and maximize building performance. The designer translates individual worker needs into physical space.

The recent steady rise (approximately 7 percent) in nonresidential construction expenditure has emphasized spending on remodernization rather than new construction (Figure 1). In fact, 59 percent of the respondents in one survey indicated that their remodeling and remodernization were continuous (*Buildings* 1993). As renovation activities increase, a growing share of construction dollars is dedicated to interior design. This chapter discusses the connection between interior design and facility costs in:

1. Spatial efficiency
2. Worker satisfaction
3. Ergonomics
4. Total life-cycle costs.

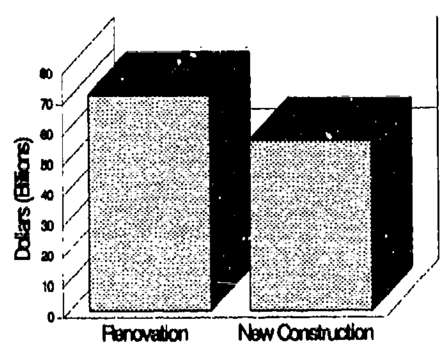


Figure 1. Cost comparison of renovation vs. new construction, 1992.

Spatial Efficiency

In the mid-1980s the government began focusing on reducing workspace requirements and renter costs, to achieve greater

economies. Maximizing a facility's usable floor area became critical, because by increasing capacity one could postpone or eliminate the need for additional facilities. Increasing usable floor area also meant maximizing cost-efficiency. With more than 206 major installations and 12.4 million acres* of real estate valued at over $181 billion, the Army can exploit interior design to produce a dramatic rise in interior space without acquiring more real property. Interior design can substantially boost spatial efficiency through:

1. Product specification
2. Workstation planning
3. Facility planning.

Product Specification Issues and Implications

Product specification covers a broad range of issues, including materials and finishes, technology, furnishings, and accessories. Of these items, furniture has the most direct effect on a facility's usable floor area.

While there is a large variety in the types of furniture available, the two fundamental types are *systems furniture* and *conventional furniture*. Systems furniture comprises a series of connected, movable partitions supporting worksurfaces, storage units, and other components (e.g., mobile pedestals). It generally includes wire and cable-management capabilities. Conventional furniture is a collection of independent components used to accommodate traditional office equipment and activities. Components are generally freestanding. They offer limited wire management capability and individual adjustability.

First costs vary significantly among furniture types. Often, furniture types are used in combination, but careful integration by the designer is required. Interior designers provide value by offering design-based knowledge of the products and experience in how these products interact with the interior building environment. Application of the designer's knowledge and experience can have considerable cost benefits.

Figure 2 demonstrates the effects of specifying different furniture systems. All three layouts provide a "typical" workstation, consisting of 10 linear feet of worksurface capable of accommodating a video display terminal (VDT), two pedestals, 6 linear feet of book/binder storage, a guest chair, and a desk chair.

* U.S. standard units of measure are used throughout this report. A table of metric conversion factors can be found on page 102.

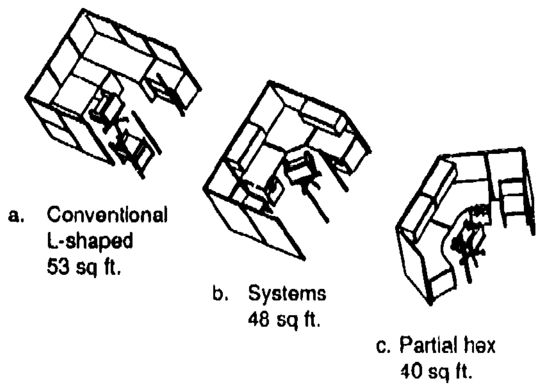


Figure 2. Differing space needs of three similar workstations.

Depending on the type of furniture specified, this workstation can require from 40 to 53 sq ft.

Some types of furniture have greater space-saving capabilities than others. Because conventional furniture components are floor-supported with conventional furniture (Figure 2a), the workstation requires 53 sq ft to accommodate the freestanding desks and storage units. The panel-supported systems furniture (Figure 2b) requires only 48 sq ft. The cost difference between these two systems for rent and operations and maintenance (O&M) is \$45.95 per year. For a facility with 100 workstations, this would amount to an annual savings of approximately \$4595.00.

Costs are based on \$9.19/sq ft (1991 average combined cost for rental and O&M, from *Facilities*). Costs of furniture systems are not included. Often furniture justification results in an additional cost savings for systems furniture when amortized over an 8-year life-cycle cost.

Special furniture applications can further increase the capacity of interior space. This is shown in Figure 2c, the most condensed layout. It uses part of a unique systems furniture module—a hexagon module—to accommodate all the components in only 40 sq ft of floor area. Although it appears to be most efficient in terms of space, it should be noted that hexagon modules can create pockets of compromised space in rectilinear buildings. The interior designer will know how best to use this and other special configurations to maximize usable space.

Interior design is crucial when specifying these systems, which generally have the highest first costs. Design principles may be used for cost justification by documenting:

1. Workstation efficiency—ensuring that the product increases usable floor area and facilitates the worker's task requirements

2. Facility efficiency—ensuring that the product does not increase circulation requirements for the facility, increase storage requirements for the facility (by eliminating workstation storage), or create unusable dead space.

Furniture specified with wire management capabilities can increase usable floor area by decreasing the number of required supply chases. Specifying components that take advantage of vertical space can reduce the amount of required floor area, but stacking components vertically can also increase the costs by imposing additional loads: wall-mounted storage units can pull out portions of walls or overturn panel runs. Applying interior design principles to product specification offers the following cost advantages:

1. Knowledge of product types
   - limits liability arising from incorrect product specification
   - limits cost overruns due to change orders (i.e., restocking fees on returnable products)
   - ensures products are capable of providing proper clearances for equipment.

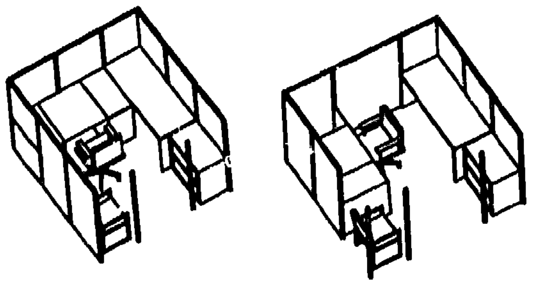
2. Understanding economic implications of various systems and layouts
   - comparative costs of operating the heating, ventilating, and air conditioning (HVAC) system using different furniture
   - costs of any additional structural reinforcement required.

Workstation Planning

Interior designers work with individuals to optimize workstation layouts. Special job requirements constrain the design to some degree, but a building's net floor area can be optimized by manipulating workstation components, points of entry, and workstation shape. The effects of workstation planning translate directly into dollars.

Manipulating Component Layout. By arranging components, the amount of floor area required can vary dramatically (Figure 3). This figure illustrates that, simply by turning a desk 90 degrees, one can gain 7 sq ft per workstation. Based on the cost assumptions discussed for Figure 2, this difference comes to \$64.33 per workstation, or, for 100 workstations, \$6433.00 annually.

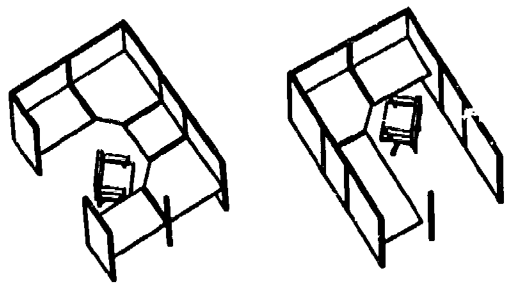
Entry Point. The location of a workstation's entry point offers a dramatic example of efficient planning when worksurface to workstation ratios are compared (Figure 4). Figure 4a provides central entry along the length of the workstation, while Figure 4b provides corner entry along the width of the workstation. Each workstation measures 6 ft by 8 ft, and uses systems furniture to provide the maximum worksurface area the space will provide. This translates to 16 linear feet of worksurface in Figure 4a and 12 linear feet in Figure 4b. Assuming a 2-ft



a. Conventional L-shaped 53 sq ft.

b. Conventional front-to-back 60 sq ft.

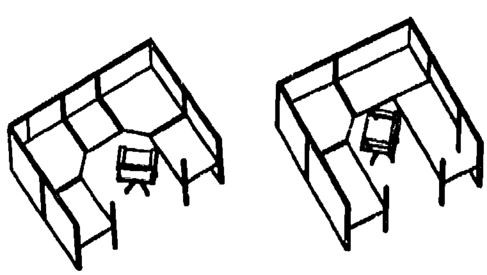
Figure 3. Different layouts for similar workstations require different space.



a. Centralized entry worksurface: 16 lin. ft.

b. Corner entry worksurface: 12 lin. ft.

Figure 4. Different points of entry produce different worksurface-to-workstation efficiencies.



a. 6×8-ft. workstation worksurface: 16 lin. ft.

b. 7×7-ft. workstation worksurface: 17 lin. ft.

Figure 5. Different shapes produce different worksurface-to-workstation efficiencies.

average worksurface depth, the worksurface-to-workstation ratio is 66 percent for Figure 4a, but only 50 percent for Figure 4b.

Workstation Shape. Shape also contributes to workstation efficiency (Figure 5). Both examples consist of a workstation of approximately 48 sq ft, but actual dimensions vary (6 ft by 8 ft in Figure 5a and 7 ft by 7 ft in Figure 5b). Both workstations offer the maximum worksurface areas (see discussion in Point of Entry). The result is, the workstation in Figure 5a gives 16 linear feet of worksurface, while the workstation in Figure 5b gives 17 linear feet. This renders a worksurface-to-workstation ratio of 66 percent for Figure 5a and 69 percent (slightly more efficient) for Figure 5b.

Workstation Type. Private offices require more space than comparable workstations in open plans because of enclosing walls. Moving a workstation from a private office to an open plan office, typically yields a 25 percent space savings. However, middle and lower managers often have difficulty making this transition for various reasons (Francis et al. 1987).

Implication of Design Solutions for Workstation Planning

Facility design is a tool to determine which of the many possible solutions resolves a problem most effectively, as shown by the following examples.

Continuous Worksurfaces. Providing full use of the workstation's perimeter can limit the amount of space lost to circulation. As a result, workstation size can be decreased, increasing the capacity of a given facility. Interior design is valuable when it coordinates the following variables for continuous worksurfaces:

1. Job types—certain tasks require specific (i.e., front-to-back) arrangements.

2. Worksurface heights and widths—mounting heights and component dimensions vary with and between products.

3. Clear kneespace—using corners of workstations requires the user to have clearance under components (not straddle worksurface support).

4. Access to wire management—worksurfaces must not block the workstation's wire management.

5. Existing furniture—can eliminate the possibility of continuous worksurfaces.

Centralized Point of Entry. This also maximizes workstation efficiency by allowing maximum use of the workstation's perimeter. The following variables can restrict or dictate the location of a workstation's point of entry:

1. Facility plan:
   a. Providing the maximum number of workstations
   b. Ensuring workstation acoustic privacy (no facing cubical openings)
   c. Ensuring panel stability.

2. Existing furniture—accommodating component and spatial efficiency.

Workstation Dimensions Based on Component Dimensions. Circulation in a workstation should be minimized. Workstation efficiency should not be reduced due to furniture arrangement problems created by a need to work around static elements, e.g., doors, windows, or electrical outlets.

Facility Planning

The use of interior design can also increase the efficiency of the facility as a whole. Planning concepts are based on maximizing productivity (see "Worker Satisfaction"), mechanical/electrical efficiency (see "The Value of Interior Design Technology"), and usable floor area. This section discusses how several planning concepts affect usable floor area.

Individual Workstations. These are workstations occupied by a single person. They are typically enclosed by ceiling high or screen partitions. In traditional office plans, they may be referred to as private offices, and are generally space intensive.

Team Workstations. These are multiple occupancy workstations, typically enclosed by ceiling-high or screen partitions.

Just-in-Time Planning. This concept, also known as *hoteling*, applies to workers that occupy their offices for only a fraction of the workday. It has also developed with recent advances in technology, allowing many workers to conduct business from remote locations. Hoteling assigns offices to workers on a temporary basis (e.g., daily, weekly). Workers simply call and let the office know when they need a workstation and they are given a fully equipped (even with personal items such as pictures) workspace. By creating only enough workstations to satisfy an average worker load, facilities can reduce their size by eliminating the number of unoccupied workstations.

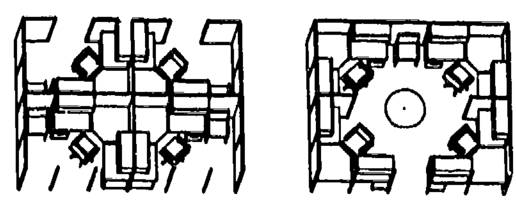
Effects of Facility Planning

Generally, one can expect 10 to 20 percent inefficiency for private offices when a group moves into a building not designed for them. Interior design plays a crucial role in increasing the efficiency of a building by working with individuals to maximize the following:

Circulation Requirements. Interior design increases building efficiency by reducing the amount of space dedicated to circulation. Figure 6 shows the effects of individual and team planning on circulation requirements. Both approaches use systems furniture and provide the user with 10 linear feet of worksurface.

Individual Workstations. The individual workstation approach shown in Figure 6a requires 204 sq ft to accommodate four typical workstations. In addition, it requires a corridor on two sides of the workgroup. This corridor is a minimum of 44 in. wide.

Team Workstations. If, however, a team workstation approach (Figure 6b)



a. Individual workstation planning: 204 sq. ft.

b. Team workstation planning: 180 sq. ft.

Figure 6. Individual and team workstation approach.

is used, only 180 sq ft is required to accommodate four workstations because circulation is shared between the users. Furthermore, an access corridor on only one side is required, reducing the amount of required circulation space for the facility. Although the team workstation shows only one guest chair, additional chairs can be brought into the station and grouped around a center table (a benefit not present in the single workstation). The team approach is highly effective in reducing circulation requirements, thus increasing usable floor area. In this case, over 25 sq ft per workgroup was gained, which translates into $5743.75 for a 100-person facility based on costs outlined in Workstation Planning.

Application of the Hoteling Concept. Hoteling works in conjunction with either of the two layouts shown in Figure 6. If, for example, a building has an average occupancy level of 75 percent, one may reduce facility size by 20 percent (leaving room for additional storage and peak requirements). Based on costs outlined in Workstation Planning, for every 100 persons, this would amount to a savings of $9373.80 for an individual planning approach (Figure 6a) and $8271.00 for a team planning approach (Figure 6b).

A Case Study. The Appendix to this report describes the Humphreys Engineer Center Support Activity (HECSA) case study, which is an example of efficient planning to maximize usable square floor area. Although reconfiguration did not decrease the circulation to gross floor area ratio, clearly defining circulation paths, reducing the number of walled offices, and complying with code increased both the building's and workers' operational efficiency (see "Workstation/Office Efficiency").

Reconfiguration also freed over 460 sq ft of space for additional programming (conference rooms, files, workstations, support areas), and in this respect increased spatial capacity. Based on 1991 costs (average combined cost for rental and O&M) at $9.19 per sq ft, the facility gains over $4227.40 each year in long-term revenue. Costs were optimized in the short term by eliminating the expense of expanding the existing gross square footage (either through rental or construction) to accommodate the organization's growth.

Implications of Design Solutions for Facility Planning

Productivity can be adversely affected by poor facility planning. Interior design is important because it investigates the planning concepts most suitable for a given facility—integrating individual task requirements with space optimization, as the following suggested solutions illustrate.

Reduce Circulation Space. Reducing the amount of space dedicated to circulation can increase a facility's efficiency. Interior design offers several ways to achieve the greatest economies by evaluating planning concepts based on:

1. Increasing usable floor area
2. Increasing worker productivity
3. Facilitating job/task requirements.

Reduce Enclosing Walls. Reducing the number of enclosing walls can also affect a facility's efficiency, either positively or negatively. Interior design principles can help determine which walls should be removed. Usable floor area may be increased 25 percent by removing the appropriate walls. However, worker satisfaction may be adversely affected by removing walls, which are often seen as status symbols for middle and upper management. Furthermore, removing walls may also reduce acoustic privacy and affect productivity levels.

Reduce the Number of Workstations. Reducing the number of required workstations can decrease the amount of space a facility requires and interior design principles provide a way to apply this variable effectively. The amount of floor area that can be reduced should be compared with the amount of additional floor area required for storage of personal items. Also, a comparison of the productivity levels of workers with personal workstations with those with shared workstations can reveal productivity implications. Also, it is necessary to evaluate how different jobs or tasks will be affected by a shared work environment.

Worker Satisfaction

A facility's efficiency is determined by how it reduces labor costs by increasing productivity; the value of interior design is in increasing productivity levels. Analyses shows that increasing individual productivity levels by 3 to 5 percent can yield enough cost benefit to justify almost any change to the workplace. The vast majority of a worker's time (over 80 percent) is spent inside the building. Interior design is essential in providing suitable work environments because it manipulates design elements such as walls, floors, and ceilings to physically and psychologically affect one's perception of the work environment. Properly employed interior design can be cost beneficial, because it offers ways to increase productivity through increasing worker satisfaction.

Causes of Worker Satisfaction

Worker satisfaction depends on individual interpretations of the built environment. It varies subjectively from user to user and because of this, worker satisfaction is one of the most difficult variables in the workplace to predict or control. Interior designers combine their knowledge of design elements with organizational and industrial psychology to increase worker satisfaction by attempting to control the following variables:

1. Physical interaction with the environment (worksurface heights or lighting conditions)
2. Psychological impact of design elements (colors, spatial proportions, environmental conditions)
3. Workflow (physical motions required, quality of supervision, amount of work)
4. Health problems (back problems, repetitive stress injuries).

Effects of Worker Satisfaction

Studies from the Buffalo Organization for Social and Technological Innovation (BOSTI) and USACERL show that workers who feel better about the work environment are correspondingly more productive. Because the worker's value is directly linked to productivity, interior design attempts to increase worker satisfaction by manipulating interior elements, and in turn, to gain cost efficiency for the facility. The effects of this can be seen in the following areas:

Type of Furniture. The type and quality of furniture provided can greatly influence worker satisfaction. Early studies at USACERL that analyzed the contributions of the physical setting on office productivity (Francis et al., September 1986) directly linked the type of furniture system provided to worker satisfaction and productivity levels (Figure 7).

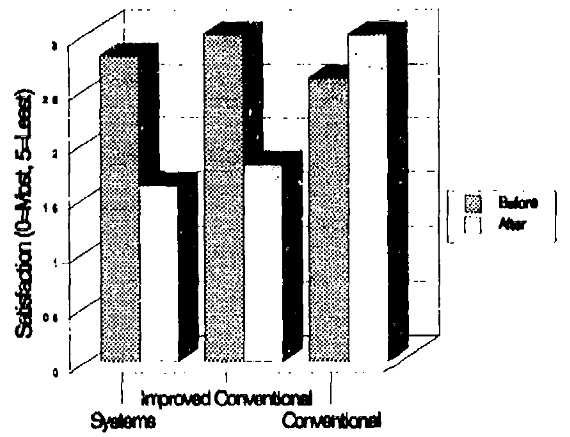


Figure 7. Worker satisfaction with furniture systems.

Spatial Perception. The amount of space allocated to an individual also plays a significant part in worker satisfaction. Workstation size is often associated with status. The larger the space, the more an individual's sense of self-importance, or morale is raised. Interior design creates value by using design prin-

ciples to manipulate spatial perceptions without increasing square footage. These principles are interdependent, and as a result, interior design plays a crucial role in foreseeing psychological as well as physical outcomes. Some of these principles and their effects are:

- Workstation Type. The type of workstation provided directly affects productivity. As mentioned in "Space Planning," workflow often dictates the arrangement of space. For example, some tasks require team workstations, while others require individual workstations. Workflow can also dictate facility planning as seen in private vs. open planning concepts. However, individual perceptions also play a significant role in determining what type of workstation is provided. Private offices are often seen as status symbols. As a result, worker satisfaction (especially among middle management) may decline if these users are placed in functionally more efficient multiple occupancy spaces.

- Workstation Shape. The shape of the space can also affect the perception of its size. In general, workstations where wall junctions have obtuse angles (such as 120 degrees) appear larger than workstations of equal square footage and where wall junctions have acute angles (such as 90 degrees). For example, a circular room will always appear larger than a square room of the same area.

- Color. Color psychologically alters the perception of space—altering the apparent size and dimension of space and also affecting an individual's mood. For example, cool colors expand spatial appearance and provide a calm atmosphere. Warm colors give intensity that may be limiting or enclosing. Interior designers can integrate these effects to create a dynamic space that is perceptually larger. Interior design also influences worker satisfaction by integrating colors with organizational psychology—creating a space that is neither too intense (which may cause fatigue), too static, or too melancholy.

- Light. Light plays a crucial role in worker satisfaction. Dark, unlit spaces are associated with safety problems, while moderately bright spaces have psychologically positive connotations, and also increase productivity. Note that quantity and quality of light differ distinctly. Simple addition of more light does not necessarily alleviate light quantity problems if the added light has the wrong color, type, or position. Interior design creates value by helping to determine the proper light configuration to increase worker satisfaction and to create a perception of expanded space.

- Scale. Scale refers to the relationship between space and measuring devices. The scale of a space is defined relative to the human body and other interior elements. Therefore, an object's relative proportion and size can make the surrounding space seem relatively large or small. Interior design combines knowledge of planning elements with their psychological effects to increase user satisfaction. For example, the ceiling height relative to other vertical elements in a room can make a room seem comfortable or claustrophobic.
- Texture. Texture, like scale can also influence the perception of space. Small surface patterns break up the surface, making it appear larger. Texture depends on the quality and quantity of light. For example, a flat, smooth surface provides a highly specular (mirror-like) finish that increases one's perception of space.

Privacy Issues. Productivity in the office is adversely affected by two different kinds of disturbances: infrequent or unusual noise and visual distraction. Interior design provides value by reducing unwanted distractions with design elements such as enclosures, sound absorbing treatments, or plants. Like spatial perception, privacy is often misunderstood—wall offices are incorrectly assumed to give more privacy, and therefore have increased status. Interior design can offer alternative configurations that minimize disturbance and also increase worker satisfaction in open office plans.

Environment. Perhaps the most critical factor affecting worker satisfaction is the environmental condition of the workplace, especially the lighting (visual conditions) and HVAC (thermal conditions). Interior design coordinates environmental systems with functional requirements to optimize worker satisfaction (see the "Value of Interior Design Technology").

User Participation. Interior design is an interactive process between designers and users. When users participate in the design process, they are given a greater sense of self-worth and are often more satisfied with the final facility design. Involving users also ensures that the proper functional requirements are obtained. Functional requirements not only affect the organizational efficiency of the facility, but also individual satisfaction/productivity levels. A case study involving HECSA (see the Appendix to this report) showed that, because users were not asked about thermal conditions in their workstations, the functional requirements for thermal control were incorrectly determined. As a result, both worker satisfaction and productivity levels were adversely affected (see Figure A1 and the following sections).

Churn Rate. The churn rate (the percentage of worker turnover per year) also affects a facility's productivity level. This worker turnover can include transfers within a facility as well as workers leaving a facility. The higher the churn rate, the lower the productivity of a facility because of downtime (rewiring, reconfiguring), retraining, and acclimating to a new environment. Note that churn rates in government facilities (15 percent) are considerably less than in private facilities (40 percent).

Stress. Stress stems from physical constraints as well as psychological pressure in the work environment. Physical constraints such as improperly mounted equipment and repetitive tasks can overstress muscles and physically injure the worker, thus lowering productivity. Psychological constraints such as heavy work loads and poor supervision can lower productivity levels and even affect a facility's churn rate. Figure 8 shows the extent of stress in the workplace, as demonstrated by a poll of 600 full-time workers conducted by a Northwestern National Life Insurance Company (Cohen 1982). Here, over one-third of the workers stated they seriously considered or had quit their job because of stress. More dramatically, it shows that almost 70 percent of the workers felt stress had made them less productive. Use of interior design principles (also see "Spatial Perception") can reduce stress in the workplace through product specification and space planning.

Health Problems. Health problems affect productivity by physically limiting the worker's output. Health problems can also affect productivity less tangibly by lowering worker satisfaction. This results in increased operational costs for a facility as fatigue and/or absenteeism is combined with increased medical and legal expenses. Specific health problems are discussed in detail in Chapter 4, "Health Related Issues."

Implications of Design Solutions for Worker Satisfaction

Because worker satisfaction is influenced by individual perceptions, it is hard to determine a fixed set of variables that can be adjusted to increase satisfaction. This is demonstrated by several broad suggestions.

Integration of Design Elements. Design elements are used in combination to add variety to a given space (to

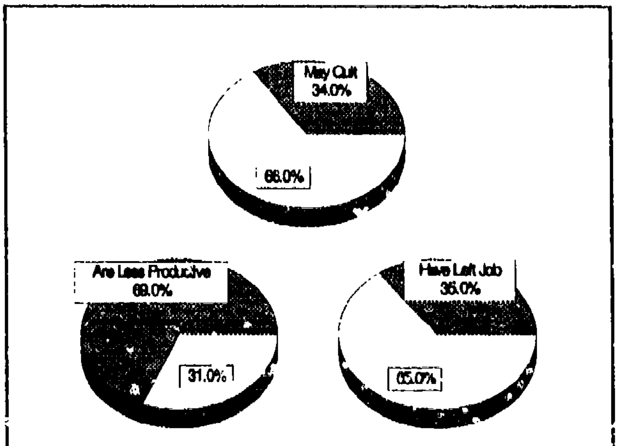


Figure 8. Effects of stress on workforce.

avoid stagnation). Because these elements are interdependent, they must be fully integrated. The perception of any given space is a direct result of the elements in that space. For example:

- Dark ceilings (vertical planning elements integrated with color) lower a room's apparent height. Cool, bright surfaces make a ceiling appear higher.

- Smooth finishes tend to make spaces appear more open; however, they may also produce a glare that can decrease productivity. Highly textured surfaces provide a matte finish that reduces glare, but this diffusion also reduces the clarity/crispness of the object.

- Obtuse wall angles increase one's perception of space, but also have the tendency to create unused "dead" space. Interior design is valuable in restricting the amount of dead space created via planning concepts.

Provide White Noise. White noise is based on the theory that the frequency at which noise is emitted, not the decibels, is distracting. Constant hums are "tuned out" as background noise. White noise emits a constant low hum that allows workers to interact while still maintaining a high degree of privacy. Because white noise systems are expensive to install, interior design can integrate the concept of white noise into the work environment inexpensively with design elements such as HVAC systems.

Provide Visual Privacy. Visual privacy can be accomplished in a variety of ways: partitions, fully enclosed offices' placement of furnishings, or plants. These options vary in the amount of floor area required, the amount of user interaction permitted, as well as in status. Interior design adds value by determining the design element that will most effectively increase worker satisfaction and productivity in the least amount of space.

Gather Information. This is critical in establishing not only functional requirements, but also individual preferences. Interior designers can ensure they reduce stress by gathering information and providing:

1. Layouts with proper functional requirements, where:
   a. Workflow is aided by a good facility plan, workstation layout, and worksurface height
   b. Adequate HVAC control is provided

2. Products that facilitate the user.

Specify Ergonomically Designed Products. Ergonomic products help reduce stress and fatigue by supporting the user's actions. Proper specification of these products can increase worker satisfaction and productivity. Interior design adds value by determining those products that are actually beneficial to the user.

Workplace Ergonomics

Ergonomics is the fit and measure of the human body to its environment. The majority of ergonomic problems are concentrated in blue collar workplaces (assembly line, meat packing, etc); however, ergonomics also applies to the office environment. Within the past 3 to 5 years, the term "ergonomics" has evolved into a buzz word of sorts. Interestingly, this has corresponded with the increased costs associated with health disorders and liability issues. Although studies have shown a correlation between work environment and visual/musculoskeletal fatigue, many "ergonomic" products on the market offer few benefits, and must be properly adjusted to reduce the danger of repetitive stress injury (RSI) (Morse and Bridgeforth 1989; Slovak and Trevers 1988; Stammerjohn 1981; also discussed in discussed in Chapter 4, "Health Related Issues." Furthermore, ergonomic studies (Granjean 1984; Sauter 1987) have recently resulted in conflicting hypothesis for workstation design: many of the national standards based on early ergonomic studies (U.S. Military Standard 1472B 1974) have become either obsolete or are under further review.

Interior design is a valuable tool in eliminating wasteful spending, increasing worker productivity and further integrating facility, workstation and worker requirements because it analyzes the validity of ergonomic recommendations. The advantages interior design offers with respect to ergonomics are best illustrated in the following areas:

1. Technological advances
2. Ergonomic research
3. Current legislation
4. Current standards.

Technological Advances

The recent explosion in the technology industry has led to an increasingly complex work environment. Current construction involves planning for short term needs as well as accommodating long-term advances in technology (i.e., providing wiring capabilities/access for systems that are currently unavailable). The driving force behind these changes has been increased productivity and profits in the workplace.

Ironically, these technological advances can lower productivity by causing severe ergonomic problems—diminishing the health and satisfaction (and therefore the productivity) of the worker. Ergonomic problems have led to worker's compensation costs totalling $40 billion per year in 1992. With costs continuing to escalate, the current trend is to use technological advances to "cure" the ergonomic problems they created. Interior design is essential in ensuring that these ergonomic products actually add benefits (in terms of increased productivity and lower health problems) to the workplace, and do not cause any additional problems.

Effects of Technological Advances

Advances in technology have not only increased worker output, but also the quantity and speed of repetitive tasks. Computer networking systems allow workers to spend more time in their workspace, which has also increased both physical and psychological stresses. Interior designers provide value by offering experience in how technological advances affect the individual worker. The application of this knowledge and experience can have considerable benefits.

Product Specification. Not all ergonomic products provide solutions. From 1991 to mid-1993 there has been a 150 percent increase in the number of products specifically designed for keyboard and data-entry people. Some of these products are erroneously marketed as ergonomically beneficial. Other ergonomic products are not properly used because of lack of training or intricate adjustment features. Interior design can be used to determine and specify products that provide real value to the user.

In Morse and Bridgeforth's (1988) assessment of Cumulative Trauma Disorders (CTD) in Santa Clara County court clerks, it was discovered that the "ergonomic" chair used as a standard was inappropriate for supporting work done by the clerks.* Had the product been specified based on job requirements, incompatible and inappropriate features (such as arms) may have been eliminated. For the 14-courtroom facility, proper specification (eliminating arms) could have saved at least $1400 (1992 costs) and provided more ergonomic support to the user.

Repetitive Stress Injury. Technological advances are often cited as the cause of many repetitive stress injuries. Because the goal of these advances is to increase worker output, automation has often forced workers to maintain static postures while performing repetitive tasks. This in turn causes muscle fatigue and lowers

* The manufacturer has since modified the chair to correct many of these deficiencies.

productivity. Interior design provides value by offering low cost solutions to these ergonomic problems by manipulating design elements (e.g., worksurface or keyboard heights) to facilitate workflow and reduce stress.

Eyestrain. Technological advances can in fact be the solution to some ergonomic problems. For example, early ergonomic problems associated with VDT workstations were predominately related to visual fatigue. As monitor resolution improved and task lighting was integrated with the work environment, the trend in ergonomic problems shifted to musculo-skeletal disorders. A 1981 study (Stammerjohn et al.) showed that 90 percent of professional employees and 84 percent of clerical employees had high complaints of visual fatigue created by screen flicker, while a later study (Slovak and Trevers 1988) indicated only 6 percent of reported problems were based on screen flicker interfering with work.

Implications of Suggested Solutions to Technological Advances

The great number of ergonomic products on the market makes interior design a vital component in achieving economical solutions to ergonomic problems. Improvements in the physical ergonomics will be effective only if organizational and job design factors are also well designed according to several factors.

Accommodate Workflow. Because proper job design and work practices lower stress, it is important to ensure that advances in technology actually help the user. This is done by providing a detailed analysis of the worker's functional, operational, and task requirements. By using knowledge and experience to specify products that integrate technology with user requirements, interior design ensures that products enhance the user's workflow. For example, integrating lighting (technology) with VDT (workflow) can help reduce glare and stress (eye fatigue).

Facilitate Individuality. Interior designers also provide value by integrating their knowledge of products with behavioral psychology. For a product to function as intended, it must be adapted to each individual user. If products are too complicated for the user to quickly understand, they may provide little ergonomic benefits, and in extreme cases may even increase stress. Interior design aims to reduce stress by specifying products that are easily adapted to each user.

Accommodate Height Adjustments. As advances in technology are incorporated into the work environment, improperly installed products can cause undue stress by forcing the user into uncomfortable positions. Interior design adds value by combining a knowledge of users' physical attributes with product specification to limit stress in the work environment.

Laws and Regulations Addressing Workplace Ergonomics

National and local legislation can regulate the type and quality of equipment used in the workplace. Such legislative guidelines can lead to additional compliance costs for facilities—costs that can be limited by effective use of interior design principles and knowledge.

National Legislation. The status of national legislation for ergonomic guidance is as follows:

1. OSHA: Although the Occupational Safety and Health Administration (OSHA) has no specific national legislation on ergonomic requirements, OSHA can make ergonomic inspections of offices (based on complaints) and cite a workplace for improper ergonomic intervention. OSHA can also cite organizations for ergonomic violations that fall under Section 5 of the General Duty Clause of the Occupational Safety and Health Act of 1970. Statements made by OSHA at the National Safety Council's Symposium on Ergonomics (5 November 1992) outlined their expectations for ergonomic compliance. The role of OSHA is to ensure that organizations provide an ergonomic compliance plan in the workplace. OSHA's ergonomics program begins with an industry standard that requires an "effective intervention strategy to systematically address the ergonomic hazards in the workplaces in which CTD and RMSs currently exist." It focuses on providing education, prevention, and product standards to ensure ergonomically sympathetic workplaces. It is expected that specific ergonomic legislation will be passed within the next 2 years.

2. U.S. House of Representatives: Current House Bill 1260 provides a standard for ergonomic hazards in Section 407, and has been referred to a sub-commitee. Like OSHA, this bill requires that an educational, prevention, and employee participation program be implemented. This bill ensures work environments will be designed to meet unique individual needs through:

   a. Worksite analysis
   b. Hazard prevention and control
   c. Medical management
   d. Training and education.

Local Legislation. To date, local legislation has been relatively unsuccessful. San Francisco's 1990 ordinance (405-90) was the first in the United States to address ergonomics and its relationship with environmental conditions, workstation/chair provisions, and education of the workforce. In terms of interior design, the

ordinance stipulated that workstations must be fitted with adjustable furniture at an estimated compliance cost of between $31.5 to $76.5 million dollars spread over 4 years. The ordinance was approved in 1990 and enacted in January 1992. In February 1992, the ordinance was repealed on the grounds that such legislation is the charge of the state or federal (not local) government. A similar law has also been struck down in court in Suffolk County, NY (York 1993).

Effects of National Legislation

The goal of legislation is to limit the number of ergonomic injuries in the workplace. Although legislative bodies may differ in the specifics of their ergonomic plans, passage of respective ergonomic plans may increase facility costs as follows:

Obsolescence. Impending legislation imposes additional costs of obsolescence on many facilities. Obsolescence affects a facility not only in terms of physical furnishings and equipment, but also in terms of workflow. Interior design is valuable because it can help curb obsolescence. For example, furnishings with fixed heights can be retrofitted with adjustable features. Also, planning concepts are based on increasing productivity by accommodating workflow. Interior design inherently addresses the issue of ergonomics because it is interested in health /life/safety issues and is required to satisfy legislation.

Downtime. As workstations are modified to accommodating ergonomic changes, the facility may experience a drop in productivity. Experience shows that interior design can limit the amount of downtime a facility experiences. Interior designers specialize in a knowledge of products, installation requirements, and lead times. These areas of expertise allow interior designers to optimize the logistics of facility modifications and therefore reduce downtime.

Fines and Lawsuits. As legislative bodies become more involved with office ergonomics, legal implications are becoming clearer. Not only are most major law schools emphasizing ergonomic issues to their students, but also the number of court cases is rising. A recent court case (Goodman vs Boeing, August 1992) awarded an employee 1.6 million dollars because the company did not accommodate the employee's work-related repetitive motion injuries.

Purchasing Decisions. House Bill 1260 has provisions that affect purchasing. Specifically, purchasing decisions will not necessarily be based on lowest price; they must be made from qualified vendors. Vendors must not only cover how long

a product will last, but also must guarantee that the item will not hurt an employee.

Implications of Solutions and Legislation

Interior design aids management in understanding the guidelines set forth by legislation. It also ensures that changes made to the workplace contain facility costs and provide real benefits to the user. This is best demonstrated in the following areas:

Ergonomic Program. As mentioned, lack of an ergonomic program could result in substantial costs due to fines, lawsuits, absenteeism, and health care expenditures. The costs associated with the Australian Carpel Tunnel Epidemic (see Chapter 4, "Health Related Issues") exceeded $15 million including over $1.8 million in medical costs alone. Average 1992 annual costs of providing ergonomic programs (evaluation and training) in the United States are (Sauter 1987):

1. Small Company (up to 50 employees): $3,000 to 5,000
2. Mid-size Company (average 1000 employees): $20,000 to $40,000
3. Large Corporation (average 10,000 employees): $100,000.

These costs are small relative to worker compensation claims, which average $10,000 to $100,000 in direct expenses. The role of interior design is to limit the number of ergonomic injuries, and to provide a defense against any legal ramifications. More detail on this topic is given in Chapter 4 "Health Related Issues" of this document.

Ergonomic Training. For any ergonomic program to work (provide benefits to the user), proper training is essential. An expensive "ergonomic" chair can do more harm than good if it is not properly adjusted. Training involves:

1. Worksite analysis (determining what tasks/habits can lead to injury)
2. Education in signs, symptoms, and types of injuries that can occur
3. Education in adjusting the work environment
4. Education in proper posture
5. Education in proper operation of equipment.

As with the other categories, cost of training employees can vary from quite expensive ($150 an hour for an outside contractor) to moderate (purchasing a video or having another employee already knowledgeable inform the user on the mentioned topics), to inexpensive (sending out memos, mounting safety posters). Although training is essential to any ergonomic program, interior design can help

curb the costs of training services by specifying furnishings that facilitate adjustability and encourage proper work habits.

Integration with Existing Standards and Furnishings. Interior design also adds value by integrating ergonomic modifications to coincide with existing facility standards and furniture. The use of these planning principles ensures that ergonomic changes imposed by legislation minimally impact a facility's costs.

Current Standards. Because legislation gives such a generic base, specific standards are developed by national trades and/or organizations. Currently, the only National Standard for ergonomics is that published by the American National Standards Institute (ANSI) in conjunction with the Human Factors Society: ANSI/HFS 100-1988 "American National Standard for Human Factors Engineering of Visual Display Terminal Workstations." A technical standard outlines minimum requirements for VDT workstations and makes some assumptions as to the posture and physical attributes of the user. This standard is based on results from a 1974 military document and is currently (since 1992) in the process of being revised to:

1. Address the needs of those outside the 5th to 95th percentile
2. Push ownership to Health & Safety, Facilities Groups
3. Allow multiple solutions (i.e., chair adjustments)
4. Provide recommendations for four working postures (currently only one)
5. Provide a holistic approach to ergonomic design.

Effects of Ergonomic Standards

The negative effects of implementing ergonomic standards are similar to those associated with legislation, and include obsolescence, downtime, fines and lawsuits. Because standards provide explicit dimensions and design criteria, standards also have specific effects on the planning and operation of facilities. Interior design is a useful tool in analyzing the effects of standards on productivity. Because the current standard has for the most part become outdated, interior design is also valuable in deciphering those guidelines that are actually applicable in today's facilities, for example:

Upright Posture. All ergonomic recommendations (e.g., mounting heights, viewing angles) in ANSI/HFS 100-1988 are based on the assumption that the user maintains an upright posture. Such a posture was originally taught in typing classes as ergonomically correct. But today's work force has limited formal typing experience and tends to assume a variety of postures (most commonly reclined).

Recent research (Nachemson and Elfstroem 1970) shows inclined back posture actually relieves disk pressure and facet joint strain (Figure 9). This supports the thesis that the user will naturally assume positions that create the least stress. Interior design adds value by analyzing individual work habits to determine proper mounting heights and angles for limiting stress based on individual work habits.

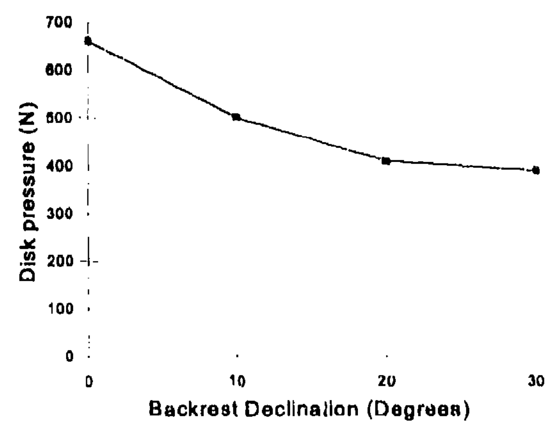


Figure 9. Effect of backrest.

Display Support Angles. Since original research was based on upright postures and often involved operators who did not look at their keyboards, early studies (U.S. Military Standard 1472B 1974; Stammerjohn, Smith, and Cohen 1981) recommended locating the display from zero and 60 degrees below the horizontal. Grandjean's later study (1984) recommends a much tighter range: between +2 and -26 degrees (Figure 10), with the screen's center located 92 to 116 cm above the floor. Current practice advocates extremes between +2 to -40 degrees with an average of -10.

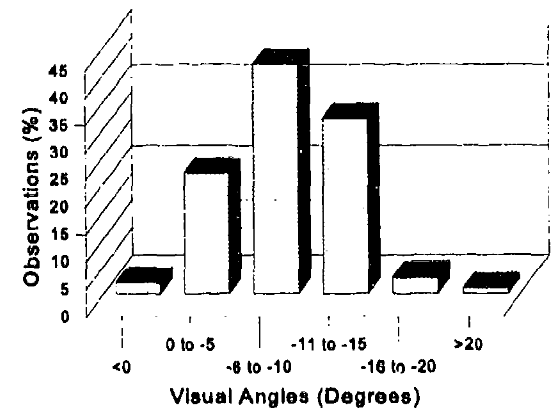


Figure 10. Preferred visual angles.

Keyboard Heights. ANSI/HFS 100-1988 currently recommends that keyboards have adjustable heights ranging from 58.5 cm to 71 cm (23 to 28 inches). Advocates of this standard cite early biofeedback results that show higher stress levels in the lumbar spine when the arms are raised above the thighs. However, later studies (Granjean 1984) reveal preferred keyboard heights (Figure 11) are actually higher than existing standards. This discrepency is due in part to outdated standards, which are based on upright postures, thicker keyboards, and users in the 5th to 95th percentile. Interior design is useful in determining optimal keyboard heights based on current equipment dimensions as well as individual work habits and physical dimensions.

Implications of Design Solutions for Ergonomic Standards

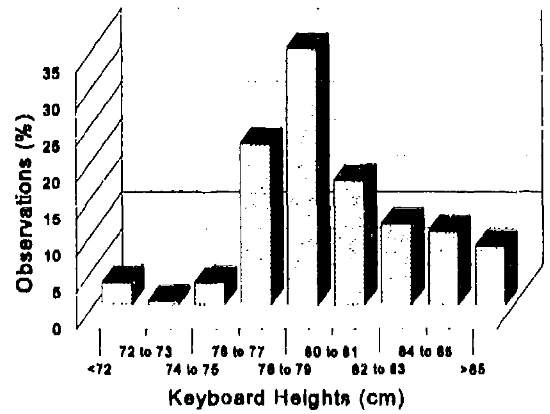


Figure 11. Preferred keyboard heights.

Interior design adds value because it follows the basic framework of ANSI/ HFS 100-1988 recommendations while providing efficient solutions based on advancing technology and research.

Adjustable Products. By specifying products with a wide range of adjustability, ergonomic support can be provided to the maximum number of users, including those outside the 5th to 95th percentile. It also lets users assume a variety of positions throughout the workday, which reduces stress and muscle fatigue. Interior design incorporates knowledge of products and individual workflow to provide specifications based on these performance issues.

VDT Triangle. Often simple adjustments to the workstation reduce eye fatigue, as the VDT triangle shows. The VDT triangle is based on the interaction of three work components: the monitor, keyboard, and document. To reduce eye strain, these three components should be placed at equal focal lengths to require a minimal amount of effort in switching between the three. Reducing the distance between the three minimizes the amount of eye motion and refocusing. Thus, by simply altering design of the work environment a low cost solution is provided.

Mount Components Based on Equipment Dimensions. Because current guidelines are based on outdated equipment data, interior design plays a vital role in determining equipment mounting heights. The interior designers' knowledge and experience in current equipment data and anthropromorphic dimensions can help interpret the intent of the standard to give the user real ergonomic support.

Ergonomic Research

As technology becomes more sophisticated (both in the study of ergonomics and VDT components), it becomes clear that many of the original ergonomic hypotheses are incorrect. Not only do some of the initial assumptions (such as an upright back posture) have detrimental effects, but as VDT components become smaller, many of the original height recommendations have become outdated.

Ergonomic research today includes biofeedback results to determine the level of muscle strain, as well as a deep understanding of human factors principles.

Effects of Ergonomic Research

Ergonomic research has created as much controversy as it has resolved—controversy in the interpretation of ergonomic results, hypotheses and products. The following describe some of the specific effects and arguments associated with ergonomic research in the workplace:

Posture. As mentioned in the previous section, initial field studies found positive associations between nonvertical work postures and musculo-skeletal problems (Duncan and Furgason 1974). However, more recent field studies found little or no support for these findings. In fact, a later study by Grandjean et al. (1984) found a reclined posture between 97 and 121 degrees actually eliminated many neck and shoulder complaints. The validity of Grandjean's 1984 field study is supported by very early biofeedback results (Nachemson and Elfstroem 1970), which indicate that the hypotheses supporting upright postures were based more on fiction than fact.

Keyboard Support. While some doubt the benefits of using keyboard drawers, many (Lechman 1990) contend these drawers:

1. Reduce stress levels by providing standard recommended mounting heights
2. Increase the adjustability/personalization of the workstation.

Others (Nusser 1990) argue that keyboard drawers can create new discomforts by:

1. Pushing the user away from the worksurface (make writing difficult)
2. Making the user strain his eyes or stretch forward to read a document
3. Giving poor wrist support, which can alleviate RSI problems
4. Applying standards developed for typewriters.

Alternative Keyboards. Ergonomic advantages provided by specifying alternative keyboards are equally as debatable. Proponents (Zipp et al. 1983; Kroemer 1993) argue that research shows that:

1. Changing keyboard positions improves productivity and health
2. Normal keyboard design approaches angle limits of the joint range
3. Normal keyboard design requires considerable static muscular work.

Opponents (Nusser 1990) argue that alternative keyboards have high first costs ($300-$700), and that:

1. They may transfer stress to arms and shoulders
2. There is no evidence that conventional keyboards cause injuries
3. There is no evidence that alternative keyboards can reduce injuries.

Viewing Angles. Recently several researchers (Kroemer 1993; Lechman 1990) in the working office environment have advocated placing the VDT below the worksurface and angled backwards. Supporters cite that the placement was:

1. Developed in accordance with ANSI/HFS 100-1988 standards to keep viewing angles between 20 and 60 degrees
2. Developed from information based on real office environments as opposed to theories developed in the laboratory
3. Allows worker to use peripheral vision
4. Reduces eye strain by placing the VDT at the same distance and level as the user's data material and keyboard.

However, equally many researchers (Nusser 1990; Kearney 1993) argue that this solution creates more problems than it solves. They claim that mounting the VDT below the worksurface:

1. Creates different focal lengths between the VDT and data materials/keyboard
2. Creates shoulder and neck problems from craning down
3. Maintains viewing angles specified by (outdated) ANSI/HFS 100-1988.

Cause of RSI. Can RSI be attributed to poor ergonomics and if so, can they be solved through better workstation design? Early studies by Stammerjohn (1981) linked RSI to a higher stress level—associating poorly designed VDT workstations with RSI. Stammerjohn concluded that properly designed ergonomic workstations would lower job stress levels, thus alleviating health problems.

However, Sauter's 1988 study of RSI in Australia indicates that these health problems, especially when reaching epidemic proportions, may be linked more to job satisfaction than to ergonomics. This is supported by a study of two telephone traffic areas (Graham, 1981-1985)*. It is interesting to note that the area of lower

* Sauter based some of his conclusions on Graham's study of one occupational group (telephonists) affected by the Australian RSI epidemic. This group was affected most predominantly—at a rate of 34.3 percent.

RSI prevalence in Graham's study had poorer ergonomic design, higher keystroke rates, similar age groups, similar posture habits and higher job satisfaction ratings on a questionnaire. Graham concluded that there was ". . . an inconsistent relationship between symptoms of 'RSI' and the ergonomics of the workstation, but a stronger relationship with job satisfaction." This is substantiated by three other studies (Ryan, Starr, Nippon Telephone and Telegraph). Although ergonomics theories such as posture, job redesign and furniture were introduced to control the Australian epidemic, it is not certain which, if any, succeeded. From this, Sauter concluded that "The contributions of ergonomics to 'RSI' . . . has been overstated within the industry" and suggested more attention be given to factors that can cause stress in the workplace.

Implications of Suggested Solutions Based on Ergonomic Research

Interior design adds value by interpreting the results of ergonomic research as it applies to worker productivity and the work environment. The bottom line is that broad-based answers ("ergonomic correctness") may not apply to specific instances. In this instance, interior design became a tool to control losses by providing efficient and workable solutions.

Facilitate Human Body Limitations. The key to any ergonomic solution is to ensure it accommodates the limitations of the human body. Specifically, this translates into support. From shoes to chairs to computers, today's market trend is to provide products that meet specific requirements. Keyboards vary in size, shape, and design (split keyboards, or those allowing angle adjustment features). Because interior design provides expertise in product types and applications, it plays a vital role in determining the most economical ergonomic solution.

Facilitate Workflow. Similarly, products are becoming more task-oriented. Chairs can be specified with closed full length arms, three quarter length arms, half arms, or no arms. They can provide numbers and degrees of height, leg, and back adjustments at prices that vary accordingly. Again, interior design provides the knowledge and experience to ensure the most economical and ergonomically beneficial product is provided. When properly used to stimulate productivity, ergonomic workstations may actually prove cost efficient in the long run.

Eliminate Discomfort. Ergonomic products do not eliminate diagnosed disorders; instead they eliminate discomfort. This is important, because it is the discomfort which causes the user to assume contorted work positions, imposing additional strain on muscles and tendons. Interior design adds value because it ensures products that eliminate discomfort. For example, if a keyboard drawer is mounted

under an existing typing return to give the user additional worksurface space or status, it may impose additional strain on the user's muscles because it is too low.

Provide Benefits Within Budget Constraints. Ergonomic products vary greatly in price. For example, a keyboard drawer can range from $12 to $200, depending on its features and construction (e.g., whether it is articulated, or includes plastic or metal parts). Before paying a potentially high cost for these furniture solutions, all options should be explored. If the only adjustable feature required is height, a $30 footrest may solve the problem better than a $500 chair or $2,000 desk.

Life-Cycle Costs

Facilities and their components must be designed to enhance mission performance, productivity, and efficiency. They must also accomodate environmentally regulations and changing missions. The previous sections primarily dealt with first costs for facilities. Since first costs reflect only 2 percent (Figure 12) of a facility's overall operating costs, planning and design decisions must also consider life-cycle costs. Such decisions must recognize the long life of today's facilities and allow upgrading to accomodate new technology and changing operations.

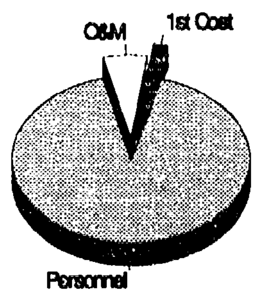


Figure 12. Analysis of overall facility costs.

Life-Cycle Cost Variables

An evaluation of life-cycle costs not only justifies, but provides insight into many design decisions. Construction takes 1 to 5 years followed by a long period of facility use until a facility becomes physically or functionally obsolete (Figure 13).

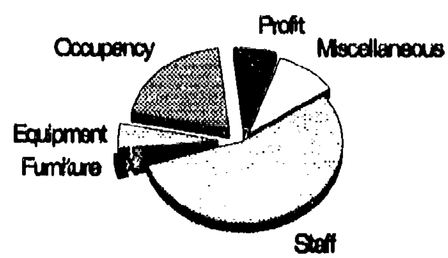


Figure 13. Typical facility operating cost budget.

During the period of facility use, one attempts to control facility costs by adjusting different life-cycle cost variables to maximize productivity and minimize expenditures. Figure 14 shows the relationship of these variables. (Exact proportions are unique to each facility.)

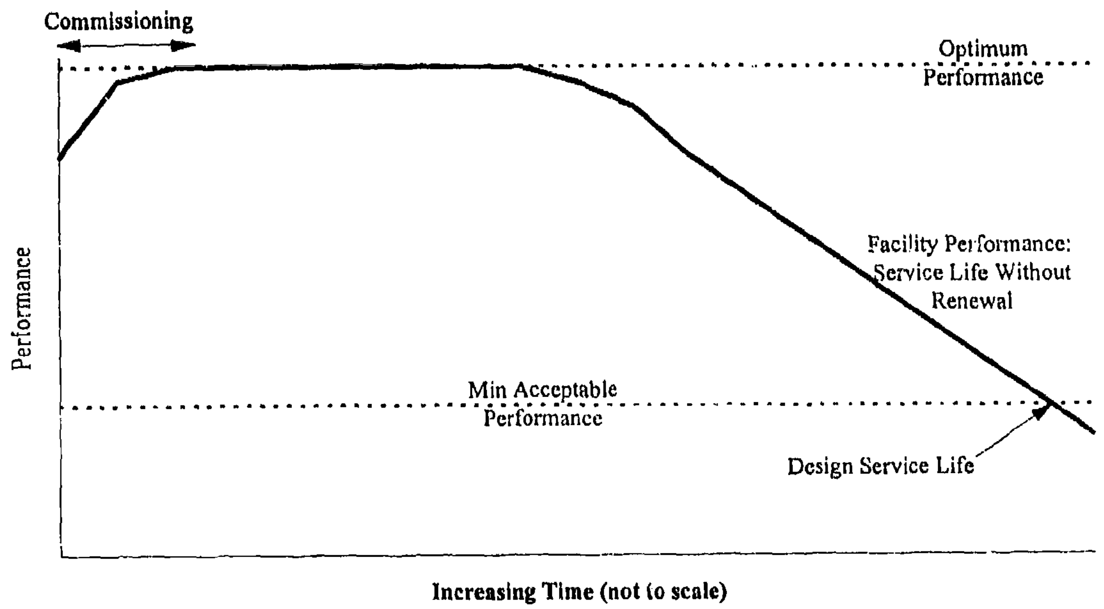


Figure 14. Conceptual view of functional obsolescence.

Furniture. As mentioned, the type of furniture can directly influence the spatial efficiency of a facility. In terms of life-cycle costs, the type of furniture can also affect the overall performance of a facility and is often the basis of justification studies. However, before any decisions can be made, the advantages and disadvantanges must be fully analyzed. A partial comparison of systems and conventional furniture is listed below:

1. Systems Furniture. Although first costs and reconfiguration costs of systems furniture are considerably higher than those of conventional furniture, systems furniture provides some long-term advantages:

    a. It allows a high degree of personal flexibility.
    b. Panel-hung worksurfaces allow clear legroom
    c. Mobile pedestals make it easy to relocate users.
    d. Panels provide visual and acoustic privacy.
    e. Furniture frames allows flexible wire management.

2. Conventional Furniture. Conventional furniture more disadvantages in terms of life-cycle costs, including:

    a. Limited degree of personal flexibility (fixed heights and pedestals)
    b. Difficulty retrofitting ergonomic accessories
    c. Limited wire management capabilities and coordination problems (desk sidepanels can easily block electrical systems).

However, conventional furniture offers some of the following advantanges in terms of life-cycle costs:

a. Quickest installation time
b. Lowest first cost
c. Structurally independent furniture (lower maintenance and repair).

Equipment Costs. Equipment costs include initial investments for such items as HVAC and security systems as well as computers, copy machines, and fax machines. These costs also include annual expenses for purchasing and upgrading equipment. Purchasing decisions factor initial investment and depreciation against the operational efficiency of a facility. Operational effiency is measure both in terms of worker performance levels and energy efficiency. For further discussion see Chapter 3, "The Value of Interior Design Technology."

Facility Occupancy Costs. Facility occupancy costs are a facility's second largest operating costs. Facility occupancy costs include: O&M costs, insurance, repairs, and utilities. These are some of the simplest variables to control because decisions made in the initial planning stages have the most direct affects on life-cycle costs.

If an area is expected to have heavy traffic patterns, a highly durable and resilient material such as asphalt plank flooring can be specified, thus reducing maintenance costs over the life of the building. Note that facility occupancy costs are directly affected by other life-cycle cost variables and therefore must be fully integrated. For example, furniture, equipment, and personnel can impose additional loads on HVAC systems, thus altering a facilities functional requirements. Operating cost calculations include a comparison with facility density, so that costs can be evaluated per employee (dollars per person per year).

Staff Costs. Staff costs include employee salary and benefits. Figures 12 and 13 show that a disproportionate amount of a facility's operating budget is spent on staff costs. For this reason, all other variables are evaluated in terms of facility density and attempt to maximize worker productivity levels.

Profit. Most of all facilities want to maximize profits. This can be done by increasing the efficiency (thus decreasing the percent of the budget spent) in any of the mentioned areas. Profits can be maximized in the short term or over the life of the building. Because the Army typically occupies its buildings for the maximum amount of time, designers focus on maximizing budget restrictions in terms of life-cycle building costs.

Effects of Life-Cycle Cost Variables

The effects of life-cycle cost variables form the basis for long-range expenditure decisions. By applying basic accounting procedures, decisions can be made to enhance a facilities long-term productivity. This is demonstrated in analyzing the effects of several life-cycle cost variables.

Staff Costs. Since staff costs constitute the bulk of a facility's life-cycle expenditures, substantial leverage can be gained by investing a small amount of extra money to increase worker productivity. Five basic productivity enhancing controls are: salaries, training, equipment, control systems, and employee benefits. Because first costs constitute only 2 percent of a facility's life-cycle costs, the greatest return on investment will be gained by a small increase in the construction budget. Also, as shown earlier, interior design increases the degree of accuracy in predicting worker productivity levels; therefore, initial investment in design decisions will give the most dramatic results.

Furniture Justification. Furniture prices vary as widely as their effects on productivity. Price differentials for a single new, furniture purchase may vary by as much as $3000. Given an average 1990 government annual compensation of $31,935 per full time employee, increasing worker productivity 2 percent can net a facility $638.70 per year per employee. Or more significantly, for every 100 employees, the facility can net $63,870.00. When this is balanced over the life of the building (taking into account depreciation, inflation, and cash flow), one can find the internal rate of return or the payback period to determine which furniture system to use. Interior design aids in this process by providing an accurate estimate of expected worker productivity levels for specific furniture systems.

Equipment Expenditures. The application of this principle can be taken one step further—into individual workstations (Figure 15.) Considering the costs of a typical workstation (equipment, salary, furnishings) can increase leverage discussed in the previous section even more. Not only does the worker's productivity generally increase, but new furnishings can promote more efficient use of the computer equipment. Facilities commonly spend $2000 to 3000 on a computer (which will probably be outdated in a year) to increase productivity by 2 percent, but find it more difficult to spend the same amount of money on furnishings, which typically last over 10 years.

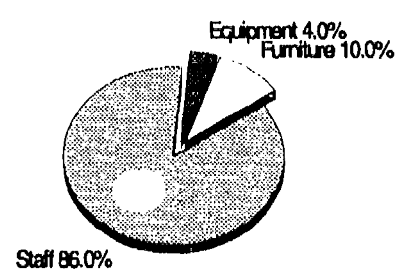


Figure 15. Workstation expenditures.

Occupancy Expenditures. Like staff costs, occupancy expenditures are best controlled in the projects initial planning stages because occupancy expenditures have the second highest ratio. However, unlike the other variables, occupancy costs are slightly more straightforward. If an area is expected to have heavy traffic patterns, a more expensive, highly durable and resilient material, such as terrazzo, can be specified, thus reducing (labor intensive) maintenance costs over the life of the building. Complications in predicting the effects of occupancy expenditures arise when other variables (furniture, equipment, building density) are not fully integrated. For example, furniture, equipment, and personnel can impose additional loads on HVAC systems, altering a facility's functional requirements.

Obsolescence. Obsolescence in facilities occurs when a given item does not measure up to current needs or expectations. This generally results from change in functional requirements over time. Interior design adds value because it can delay the effects of obsolescence by providing periodic renewals that raise performance levels and extend the service life of the item in question (Figure 16).

Implications of Design Solutions to Life-Cycle Cost Variables

Life-cycle costs can best be controlled in the design stage. Because budgets are often restricted, interior design adds value by evaluating cash flow against the following design options, thus enhancing life-cycle costs.

Incorporate Future Changes. Incorporating future facility changes into design can reduce additional annual expenditures in terms of furnishings, equipment, and occupancy costs. For example, if workstation standards for clerical workers are 60 sq ft and 90 sq ft for technicians, by standardizing workstation dimensions respectively at (6 by 10) and (9 by 10), future changes are easily facilitated. Adapting a clerical workstation into a technician workstation would require adding 3 linear feet (one 36-in. panel) along each side. Both time and money (labor costs) are saved because entire workstations do not need to be torn apart. Also, if components are specified in 36- and 48-in. modules (multiples of workstation dimensions), components can be easily reused, limiting additional purchase requirements. Of course adapting workstations as described may be limited by access requirements and the building shell.

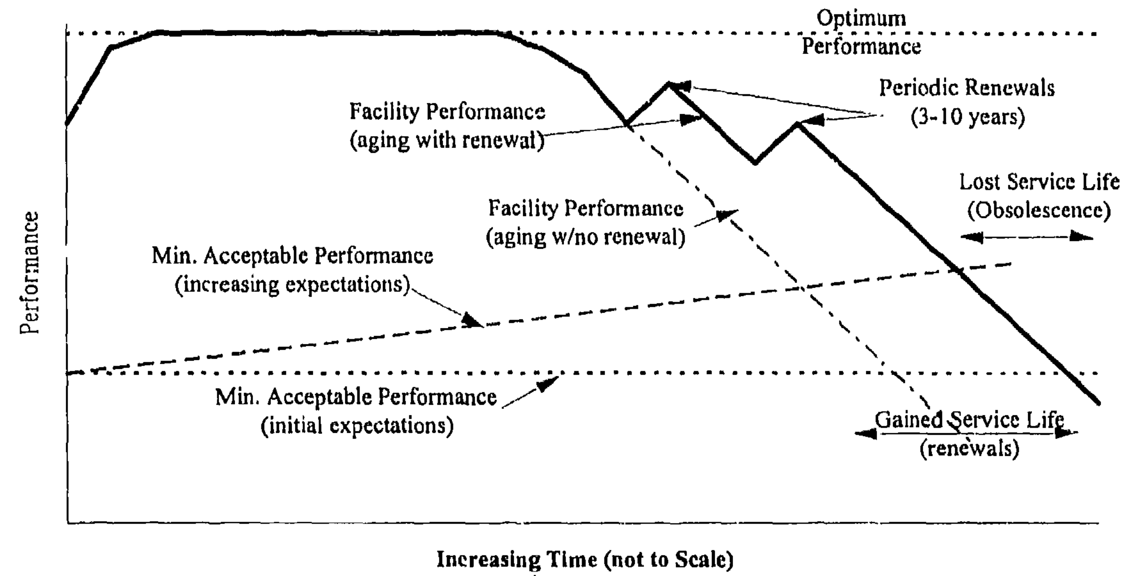


Figure 16. Factors affecting obsolescence.

Limit Product Types. Although limiting the number of product types can raise initial costs (since it causes less competition in bidding), it does facilitate the logistics of any future facility changes. Because components, particularly furniture components, are seldom interchangeable between manufacturers, limiting the number of product types on the job reduces future expenses in terms of:

1. Surveying existing furniture (what products can be used where)
2. Additional purchases (components can be reused without restrictions)
3. Coordination time (site visits, labor).

Balance Equipment Costs with Furniture Costs. As discussed earlier, productivity can be enhanced by furnishings and by equipment. Because equipment often requires proper support to increase productivity (see discussion in "Ergonomics"), appropriate furniture should be specified. Interior design adds value by predicting productivity outcomes and specifying appropriate products based on knowledge and experience.

Provide Adequate Partition Heights. Because air flow (HVAC efficiency) can be impeded by vertical elements in a space, open office plan partitions should be limited to a height of 65 in. Anderson et al. (1988) also showed that 65-in. high

partitions increase acoustical privacy while allowing natural light to penetrate the interior space. Although these partitions have higher first costs than drywall and low partitions (less than 54 in. high) by specifying 65-in. high partitions, life-cycle facility costs are lower because both productivity and building efficiency are maximized.

Provide Resilient, Low Maintenance Finishes. Specifying resilient, low maintenance finishes decreases life-cycle costs by reducing the amount of maintenance (labor, cleaning supplies) and repair required by a facility. Although these finishes often have higher first costs, they are often required by design guides and regulations (i.e., Army DG 1110-3-122). Interior design adds value by providing solid information on product types and applications, so the first costs are balanced with life-cycle costs and a facility's functional requirements maintained.

Specify Energy-Efficient Products. Likewise, specifying energy efficient products lowers life-cycle costs and facilitates compliance with environmental regulations. Chapter 3, "Value of Interior Design Technology" details this topic .

Limit Building Density. Limiting building density aids in the operating efficiency of a building's mechanical, electrical, and telecommunication systems. To save additional costs of leasing or building additional space, the decision is often made to increase the building's space. This in turn imposes additional loads on the HVAC and electrical systems, loads that the specified systems may not be able to handle efficiently. Interior design adds value by evaluating planning decisions in terms of life-cycle operating efficiency, to ensure the most economical decision.

3 The Value of Interior Design Technology

Interior architecture reflects, in part, society's ongoing efforts to create a comfortable, productive, and protected environment. The most productive human work environments are those where people are most comfortable and at ease. New building technologies have contributed to the creation and development of specialized mechanical systems to meet these ends.

The greatest asset of a company is its employees. Great effort should be spent to accommodate their basic psycho/social and physiological needs, and to provide them with the necessary tools to perform their daily functions in an efficient, effective way. An organization's competitiveness rests on its ability to maintain improved standards of support and ever advancing equipment abilities.

Designers add value in the built environment by contributing several different areas, with differing technologies. These technological areas are associated with building systems, and must be integrated with the furniture, fixtures, and equipment:

1. Wire management
2. Lighting quality and control
3. Indoor air quality and control
4. Telecommunications.

Wire Management

Administrative and technological advances of the 1980s introduced open office planning technologies, individual workstations, and personal furniture overflowing with computers, disk drives, printers, modems, copiers, fax machines, and telephones. What appears on the desktop as a neatly positioned system translates into a massive and confusing jungle of cords running throughout the office. These cords, the lifelines of modern business, must be serviced and planned for. Wire Management Systems (WMS) exist for this purpose.

Wire management is the process of designing, installing, and diagrammatically mapping the distribution systems for electronic media. Proper wire management system design is important:

1. To conserve resources
2. To simplify repairs
3. To make future office reorganizations more efficient
4. To allow for technological advancement/system growth
5. To provide optimal data transfer efficiency and quality.

Types of Wire Management Systems

Several methods distribute electronic media throughout the built environment.

Access Ducts. The access duct method consists of two in-slab systems: The Underfloor Duct and the Cellular Deck System. Both systems transfer data by connecting utility closets to office locations via trenches and grooves cut or formed at 90 degree angles in the flooring substrate (usually concrete).

Access Floors. An access floor, more commonly called a raised floor system, uses 2-ft. sq. panels seated on anchored posts. Floor heights range from 4 in. to 2 ft above the existing floor system. The plenum space formed between floor surfaces is used to run cables, HVAC Systems, and plumbing.

Dropped Ceiling. Like the access floor, dropped ceilings create a plenum space between ceiling structures. Unlike floor systems, however, there is more competition with other bulding system components for space, less accessibility, and often more difficult design issues to face.

Wireless Transfer. The relative newcomers and the growing preference in electronic media transfer are Wireless Transfer Units. They are outperforming Local Area Network (LAN) cable system counterparts. They omit loose wires altogether by broadcasting data signals with infrared transmitters and receiving the information through special adapters at individual workstations. Electrical power must be supplied through one of the other methods described above. Current trends are to use this system in conjunction with other systems.

Furniture Chases. At one time, cabling solutions limited the furniture configurability. Cable distribution, therefore, dictated rather than facilitated work processes. Modern furniture is much less restricted as it includes concealed wire

channels and prewired outlets with modular connections to facilitate easy power connection and data distribution.

The Value of Wire Management

The great influx of technology that has advanced communication, data processing, and information systems presents several problems with building aesthetics, system costs, human safety, and worker productivity. Design professionals create value in interior environments by maximizing the return on capital and manpower investments. Proper wire management systems minimize the activities that create negative impacts on these considerations such as spending time locating shorted wires, or using too much wire to accomplish a simple task. Designers consider several factors when developing a highly successful and cost effective system:

Capacity and Number. Wire management systems contribute to the ability to upgrade power supplies and data transfer mediums as future demand increases. Modern power supply limits are in the 10 to 12 amp range per four-circuit, eight-wire system. Future offices, by virtue of their technological advances and reliance on automation, may require as many as 30 amps per office line. Current practice is to supply all equipment over 10 amps independent of all other wire runs. In the future, this will become increasingly cost prohibitive, as the use of more office machinery will create higher power requirements, and ordinary wiring means provide fewer opportunities for renovation. Figure 17 demonstrates the ordinary power requirements for typical office machinery.

Designers, in recognizing the trend for greater wire capacity, tailor specific systems to meet not only today's needs, but future needs as well. For example, Steelcase 9000 Systems Furniture can accommodate up to six 1/4 in. coaxial data wires per corner cable pole (the smallest chase member in the entire unit). This permits independent lines for two telephone lines, a modem, a video communications link, fax machine, and a line for future use (Steelcase 1991, p 157). Advances in wires themselves will change the systems that govern them. Fiber optics distribute hundreds more data strings than regular wire systems in a fraction of the space, however they require longer turn radiuses and are difficult to fit in tight spaces. Allowances for changing wire types and quantities will be necessary in all future office structures.

In short, a designer's mandate for wire management systems will provide for the addition of circuits, increased quantity and quality potential of the power supply, and improved expansion space capabilities.

Flexibility. The fundamental advantage of Wire Management Systems is their ability to allow easy equipment movement and construction renovation of the interior office environment. Today's dynamic organizations often have churn rates in excess of 40 percent. This could mean several thousand hours of wire investigations, wire pulling, and technical media relocation per year for even a medium-sized company. Designers develop Wire Management Mapping Systems that detail and record where specific wires are placed and where they can most

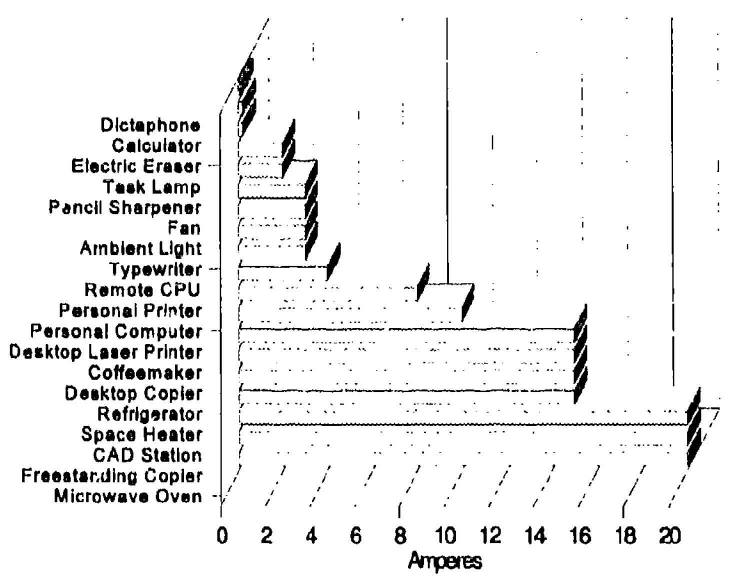


Figure 17. Power consumption of office equipment.

easily go. Outlets can be activated or deactivated depending on the current user needs. Design practices rely heavily on furniture, specifically systems furniture, to provide multiple wiring options to efficiently accommodate wire entry, exit, service, and floor plan changes.

Integrity. Offices are designed to provide an appealing environment for workers that is conducive to effective job performance and attractive to clients. Wire management systems (WMS) are an important part of maintaining the appearance of interior environments. Unlike more rigid solutions, WMS provide nondestructive access and alterations. By providing room for expansion, well-recorded wire runs, and thoroughly tested construction techniques and products, WMS can remain in their initially designed states indefinitely. The presence of WMS should be unnoticed until it is necessary to change the communication technology or configuration.

Costs. As with all building costs, the expense of managed floors, engineered ceilings, special furniture, and transmitters should be figured, not as a single purchase, but as a life-cycle cost. Wire management systems add to first costs but ultimately pay for themselves with every electrical alteration or upgrade. The initial costs of each system differ substantially. For example, first costs for in-slab systems generally cost little more than the concrete and formwork that constructs the floor. However, these costs quickly escalate with every renovation or special junction area required. Access floors generally add $7 to $24/sq ft (Means, 199, p 252) and often qualify for a tax credit in nongovernment buildings because they are not necessarily fixed or part of the structural skin, but are sometimes considered equipment. The advantage of such plenum systems is that they are easily reconfigured and maintained. Figure 18 shows the cost of a WMS over a 5-year period along with several equipment/furniture relocations and electronic renovations.

Technological Simplification. Certain communication instruments create electronic fields that must be kept separate to function properly. In recognition of this, designers use WMS with built-in shielding qualities. For example, plenum systems allow wires to be spread out over safe distances, systems furniture provides baffles, and core systems provide heavy material buffers between sensitive electronics. Less expensive wiring may be used because the WMS takes over the responsibility for protecting electronic components.

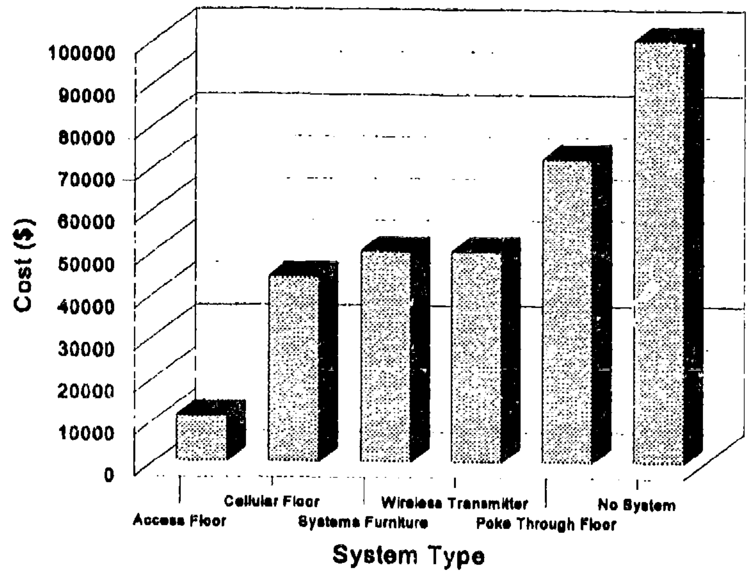


Figure 18. Estimated costs over a 5-year period.

Drawbacks of Wire Management

Wire management systems are also associated with several office shortcomings.

Wearability. One of the challenges faced by designers is to create a lasting environment. Some removable panels do not wear as well as their fixed counterparts. The use of panels for accessibility, separate flooring and ceiling systems, and modular carpeting tiles creates a special concern for the maintenance and longevity of interior office materials.

Designs involving wire management systems introduce many new parts to the office environment. Many of these parts are operable, and increase the number of joints, seams, and wearable edges that may contribute to a shorter life cycle replacement plan.

Cleanliness. Chases, especially those that share their space with air handling units, can become collection points for dust and grime. This build up of material may contribute to heat gain among electronic components, decreasing the quality and life expectancy of certain equipment. Plenum spaces can also become collection points for water and other liquids. Proper venting, drainage, and maintenance plans are required to operate WMS effectively. Designers provide for these shortcomings by specifying regular maintenance activities, access doors, and ventilation/drainage openings.

Additional Structure. As with all major building components, WMS add to the structural demands of buildings. Proper building design considers the additional impact of substructures on the built environment. All WMS add weight, which often affects ceiling heights in new and renovated buildings. Careful investigation of facility loads and dimensions is critical to ensure not only the success of access to WMS, but the success of other building systems built around the wire handlers.

Noise. Plenum spaces and chases provide echo chambers for air and structure-borne sound. Access floors, raised by metal stilts above hard floors, can become unstable and noisy. Preventative measures must be taken to ensure that simplying data transfer does not harm the human interior office environment.

Cost. The initial costs of WMS can be prohibitive. The decision must be made whether or not the long-term effects of purchasing such systems are greater than the short term need for resources. Uncertainty of future technological needs may contribute to hesitance in buying such flexibility. If office space turnover is high, if lease terms are short, and if the communication system is a candidate for upgrade, then a WMS may be an efficient option.

Coordination With Other Building Trades. Coordination between building components, furniture designs, computer networks, and electrical components becomes vital for the success and future efficiencies of such systems. Full-time personnel are often required to manage these systems and ensure tight organizational control of the placement and capabilities of communication lines.

Light and Quality Control

For many years, good office lighting was based on satisfying the most visually demanding user/task uniformly for all workers. Recent design trends, however, suggest that superior office lighting plans are based on specific models of efficient energy use. In this context, the task for today's designer is to balance light levels, quality, and control independently to meet the needs of each individual.

Lighting must be flexible enough to accommodate change. Office design now recognizes that inner office movement and differing building usage are inevitable. Offices change with personnel relocation, introduction of new types of electronic equipment, and with every attempt to cut cost and improve efficiency. Interior lighting design must not only illuminate for fast, accurate viewing, but also to produce an atmosphere conducive to thinking, talking, meeting, and learning.

Lighting design and control is vital to facility operation. Proper system configuration must accomplish the following facility-level goals:

1. Conserve energy
2. Reduce operating and maintenance costs
3. Improve worker productivity
4. Support safe and healthy working conditions
5. Provide a comfortable working atmosphere
6. Create an attractive corporate signature.

The Importance of Proper Lighting Design

More than 80 percent of our sensory experiences are visual. Few technological advancements in the interior environment can alter productivity as does lighting. Studies have shown that a drop in light quality, such as altering the light level or increasing glare, decreases worker accuracy, concentration, and output. For example, Pennsylvania Power & Light Co. (PP&L) was overlighting their Allentown drafting department, causing distractive bright spots and productivity lags. They reorganized light layouts, altered bulbs, and reduced their footcandle output from between 135 to 150 footcandles to 100 to 130 footcandles (a 74 percent savings in O&M costs) and realized a 13.2 percent increase in production drafting speed. The total value of this increase in labor output reached $72,468 annually—a 501 percent return on investment (Dubbs 1991). So, if a negative change in lighting conditions produced a 28 percent drop in worker efficiency, more time would be spent on routine tasks and error frequency would increase. Simply put, a $1 million total salary budget would increase $280,000 in costs.

Figure 19 compares average annual costs for people and lighting in a typical small office. It can be seen that an increase in lighting costs (due to upgrading current systems) would have a minor effect on the overall facility budget, but has the potential for a dramatic effect on personnel costs (General Electric, 4).

Lighting Control

Designers have traditionally used light controls to provide lighting flexibility or dramatic visual effects in office spaces. Today a major application is energy management. Simple controls such as photocells, audible sensors, timers, or motion detectors turn lights on and off independent of human intervention.

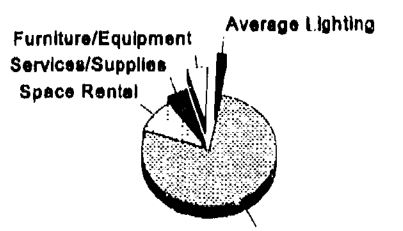


Figure 19. Total annual costs.

Lighting need not be compromised to implement specialized controls. Control options need not depend on light type. Many control systems operate multiple illumination types and a variety of nonlighting equipment simultaneously to create a desired effect. Many sophisticated facilities incorporate lighting systems into building energy operations, much like those used for HVAC. Control systems should be:

1. Multi-configurable
   a. Permit modification of the visual environment to suit a variety of simultaneous or independent activities; bright light for work, dim light for relaxation.
   b. Use specialized systems to regulate groups of lights simultaneously, to select preset levels from a single location, or operate from anywhere with a remote control.

2. Productivity-enhancing
   a. Enable workers to adjust lighting to meet their own needs, a very important factor in today's video display terminal dependent office.
   b. Permit lighting to adjust to tasks independent of visual needs, such as corrective vision requirements, length of time performing task, and work surface characteristics.
   c. Provide control of task lighting to an individual performing task.

3. Cost-reducing
   a. Allow adjustment for outdoor light conditions or work to be performed to conserve power.
   b. Use lower light levels in nonvisually intensive area's to reduce power consumption and increase bulb life.
   c. Automate power controls to mechanically discontinue operation of unnecessary lights.
   d. Downpower lights during nonwork times.
   e. Minimize use of inefficient components, such as three-way bulbs.

4. Aesthetically pleasing
   a. Highlight interest areas.
   b. Create atmosphere and mood to promote an image.

Control Options

The critical issue in designing lighting control systems is not only the selection of the proper control device to meet specific goals, but also the careful planning for how these controls are to be used and how they relate to other building systems.

The office of the future will have completely integrated control systems. Listed below are several popular lighting control options.

Timing. One powerful method of controlling facility costs is to mandate clock-sensitive switches. Once use patterns are known, many light systems can be automated to reduce power consumption or shut off during non-use times. Many office illumination systems are switched on by early arriving workers and not shut off by the last person who leaves. Night cleaning crews often arrive several hours after the last regular employee to find lights still running. Lighting kilowatt-hour savings of 25 to 50 percent can result from the installation of time-switched devices. (General Electric, 16) Figure 20 shows the power saving opportunities that may result from such methods.

Tuning. Adjusting individual luminaire type and focus to provide sufficient background light over work areas and less intense lighting in circulation and other noncritical areas can result in kilowatt-hour savings of 10 to 20 percent over uniform systems. The use of accent and vertical surface lighting can work together with tuning systems to make the office appear visually appealing as well as energy efficient. (General Electric, 16)

Daylighting. Modern offices are often designed to take advantage of natural lighting. Available controls can automatically dim interior illumination systems to standard levels to compensate for the added brightness of the sun. Such lighting systems consume less energy and realize cost savings. Systems that take advantage of daylighting must be very sophisticated and require specific zone control. Since not all areas of the office receive direct sunlight, and since sunshine is variable throughout the day, these zones must be small and quick to react to sudden changes.

Lumen Maintenance. An emphasis on housekeeping contributes to the efficiency of lighting systems. Over time, dirt collects on lumens, luminaires, and reflectors, causing bulbs to dim and work surfaces to tarnish. The net result can be wasteful power consumption due to heat build up that prematurely ages components (lowering the power-to-output capacity ratio) and a decrease in overall lighting performance caused by light rays being blocked by excessive build up of dirt particles. As much as one-half the original light level may be sacrificed in unclean fixtures. Burnout also contributes to inefficiencies. When relamping, it is more efficient to relamp groups of multiple bulb fixtures at one time, since it saves labor, and saves energy (which is usually more expensive than bulbs). It is also less expensive to replace bulbs slightly before their rated life expectancy expires rather than waiting until they burn out.

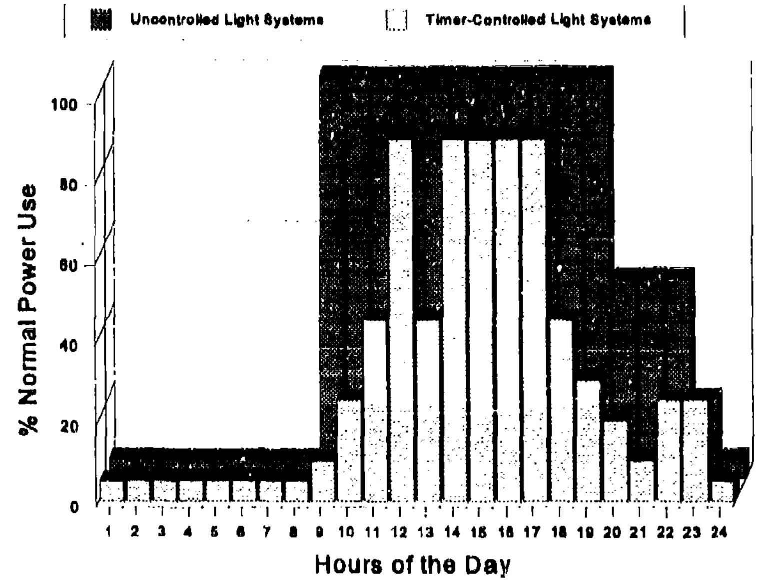


Figure 20. Savings accrued from use of timer-controlled light systems.

Two types of control systems are available to combat the effects of age and poor light fixture maintenance. The first system slightly reduces the input voltage of standard fixtures to increase the life expectancy of the bulb. As time passes and the bulbs begin to dim, the power supply to each bulb is increased to maintain a constant light level. These systems conserve energy early in their life-cycle and expend greater amounts later in their life. The second system is part of a well-governed maintenance plan where the cost versus efficient life cycles c specific lumens are known. Here, bulbs are monitored to ensure that they are operating within specific energy efficiency tolerances (realizing that lightbulbs decrease in efficiency as they age). When the lumens begin to operate at a cost that surpasses their replacement costs, they are removed and replaced with new bulbs. This system is widely used in highway and parking lot illumination systems and is gaining popularity in building interiors. In general, it is more cost efficient to relamp all bulbs at once rather than spot replace specific bulbs for an individual fixture. Most bulbs are cheaper than the labor required to install them. In either scenario, there is no substitute, nor more effective method of bulb care than regularly scheduled fixture cleaning. A clean lamp works most efficiently.

Energy Management Systems. As facilities become more complex and intelligent, lighting control systems are being used to monitor energy usage in specific facility areas, for security, and as a trigger for heating and cooling controls. To be certain, switching has become more sophisticated than a wall-mounted flip button.

Systems are now fully automated and integrated with computer-controlled smart building systems. For example, when lights are on, heat loads increase and specialized cooling systems activate to balance the temperature of the affected rooms. When movement is sensed, lights activate to aid in the safe passage of a person or to warn of a would-be intruder.

Specialty Systems. The continuous advancement of lighting technology provides several creative options for individually controlled light sources. Items such as special dimmers, wireless (infrared, ultrasonic) switching, foot buttons, touchpads, or touch screens are common in today's advanced interior environment. Control systems can be as novel and unique as their needs and ultimate user demand.

Quality and Value Through Design

The appearance, functionality, and comfort of the interior environment and how people react to it are directly related to the design quality and performance of the lighting systems they use. Realizing that over 70 percent of what office people see during the course of a day is made possible by interior lighting, it is important to ensure high quality and superior performance of illumination systems. Though many design quality factors are subjective and depend on the skill and experience of lighting designers, many system characteristics can be qualified. Specific factors may be measured and industry/user accepted specifications have been established by any of several criteria.

Glare. Glare is most often and incorrectly referred to as "too much light." Glare can be a serious problem in any open or closed office plan. The problem is usually more the direction than the amount of light. Misdirected light, coming from excessively bright luminaires or windows is often improperly shielded from peripheral view. Competent designers, in recognition of this fact, design environments that shield the eyes from direct glare by protecting sight lines within a zone of 45 degrees from the working plane and direct light sources. Because people and building elements are often spread throughout a particular space, 100 percent glare protection is not possible. Designers are, however, very effective in minimizing the discomfort, distraction, and fatigue that results from the glare effect.

Window Brightness. Windows are an excellent way to supplement regular office lighting systems. The same principles that apply to luminaires should also apply to windows. The uncertain nature of outdoor light has great potential for glaring or bright spots—even on cloudy days. Designers hedge against the problems associated with sunshine by providing adjustable shades and drapes to control

excessive illumination. Further design provisions may include the specification of low transition exterior glazing. Such systems, however, can have a negative effect on office appearance on cloudy days or during night hours as they tend to make the interior environment gloomy if the transmission of the glass is less than 50 percent.

Shadows. Shadows are necessary nonlight patterns that enable us to see shapes, textures, and colors. They are also annoyances when cast on lighted office tasks. Narrow light distribution patterns or illumination from only a few point light sources can produce dark areas and resulting discomfort. Skilled designers use broad distributive lighting as well as special design features to offset the effects of localized light sources. Shadow solutions depend on the nature of the specific office layout, including equipment. In these situations it is very important for the designer to make a workplace flexible and to allow for customization of light sources and types to balance the light level of a particular space.

Reflectance. When the silhouette of a bright object is visible on a particular task (written material or computer monitor) the contrast is reduced and the material becomes more difficult to see. This phenomenon is called a *veiling reflection*, because it appears that a veil or screen is in front of the task at hand. The resultant dual image can slow visually intensive work, lead to loss of concentration, eye strain, and physical discomfort. Reflectance is a position dependent distraction and can be controlled through careful design efforts. Reflectance is also highly dependent on materials. Some office products reflect light more easily than others and compound difficulties for design professionals. Theoretically, the easiest design solution is to reposition the task or work area to minimize negative reflections. Most office layouts do not permit such flexibility. Rather, the most widely recognized corrective measures involve modifying the lighting system and providing contrast controls for the task at hand. Technology provides us with such items as highly adjustable direct light sources and polarized computer monitor screens to provide proper illumination. Additional measures include designing spaces with special diffusers for general lighting that direct light vertically rather than horizontally throughout a room, indirect illumination that uses walls or ceilings to more evenly distribute light, and adjustable work surfaces that permit reflectance angles to be changed. Figure 21 shows the effect of light directed at a work surface from angles other than the veiling reflection zone.

Light Brightness. The Illuminating Engineering Society (IES) recommends a broad range of illuminance levels for a variety of work activities. Table 1 lists lighting range requirements recommended by the IES. Illuminance is the amount of footcandles found on the working plane.

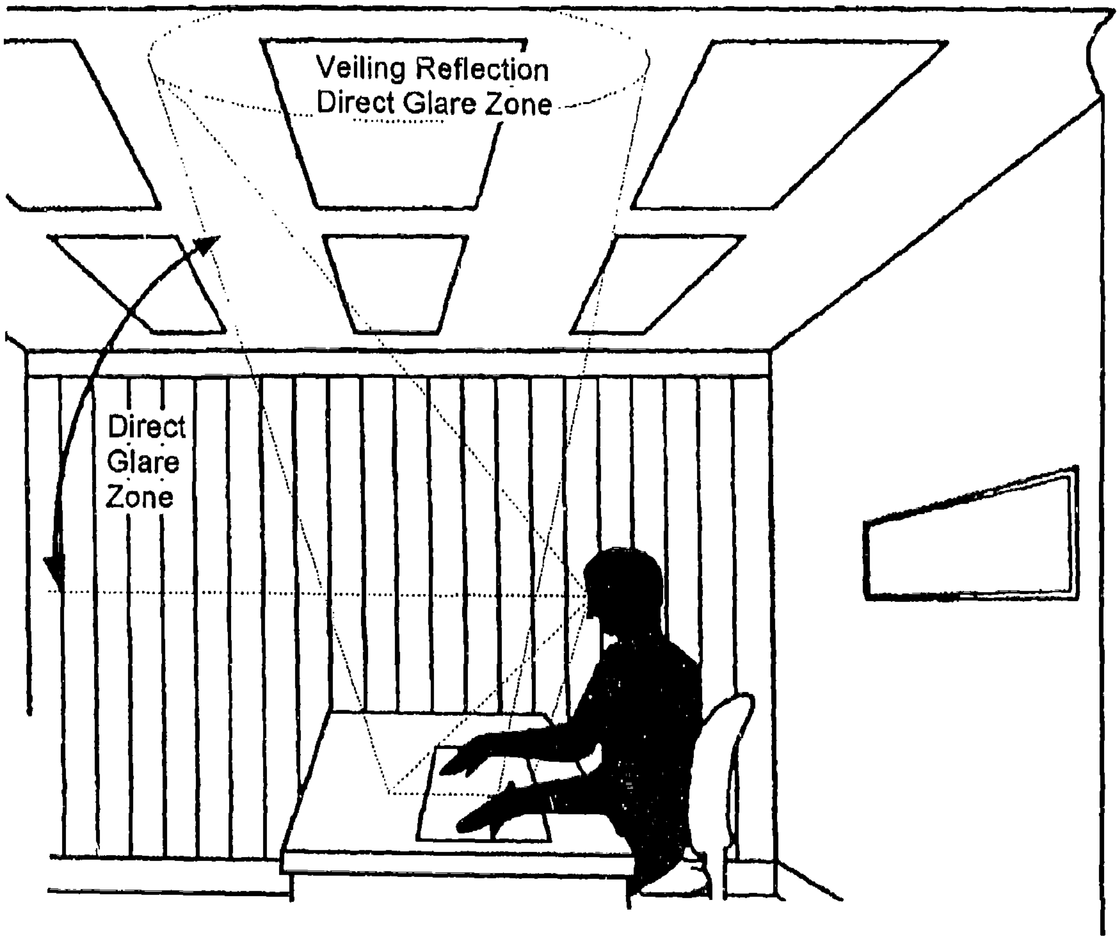


Figure 21. Effects of light directed at a worksurface.

The IES recommendations provide a guide for efficient visual performance in most office spaces. Successful lighting designs fall within IES parameters to provide adequate lighting, but the specific illuminance level is determined by weighing factors specific to the individual office climate. These weight factors are the object of many sophisticated studies, such as those conducted by the IES. Their findings suggest a relationship between lighting needs and worker age, task importance, and task difficulty. In general, as worker age increases, the need for greater lighting levels and the sensitivity to glare increase. Aging has specific effects on the human eye:

> The eye's crystalline lens grows thick and yellower as one ages, and more light is needed to penetrate the deteriorating lens. But increasing light levels for everyone in a given work environment is not necessarily the answer. You

Table 1. Summary of IES recommended illuminance levels for office lighting.

Type of Activity	Illuminance Range (Footcandles)
Working spaces where visual tasks are only occasionally performed (IES category C), e.g., lobbies, reception areas, corridors, stairs, washrooms, circulation areas	10 – 15 – 20
Task lighting involving performance of visual tasks of high contrast or large size (IES category D), e.g., reading newsprint, typed originals, 8-10 pt print, impact printing (good ribbon), ballpoint or felt tip pen, conference rooms, library areas, general filing	20 – 30 – 50
Task lighting involving performance of visual tasks of medium contrast or small size (IES category E), e.g., mail sorting, reading thermal printing, xerography, 6-pt print, drafting with high-contrast media, photographic work (moderate detail), writing (#3 pencil and softer)	50 – 75 – 100
Task lighting involving performance of visual tasks of low contrast or very small size (IES category F), e.g., drafting (low contrast media), charting, graphing, reading poor thermal copy	100 – 150 – 200

might think instead about using more flexible light systems. With a desk or task lamps as a supplement to a general lighting system you can get a lot more light inexpensively (Jankowski 1992, p 23).

The importance of the task (how critical or expensive visual mistakes are) mandates greater light levels for more critical activities. Another important design consideration is lighting mix. Effective system design incorporates both direct and indirect lighting sources to illuminate both open and closed offices. Most manufacturers recommend a mix of five parts direct lighting to one part ambient lighting.

Color. White light is luminous energy that contains a mixture of wavelengths that are perceived as color when the eye transforms this energy into a signal for the brain. People have color preferences and see things in different ways. Therefore, the ability of a lighting system to render a space is subjective and a matter of opinion. The variables open to designers that affect one's sense of color include chromaticity and rendering ability.

Chromaticity describes the temperature, the visual "warmth" or "coolness" of a particular light source. Chromaticity is measured in Kelvins (K) and typically falls between 2800 and 7500K. All values above 4000K are considered cool. All

values from 3500 to 4000K are considered neutral. Design professionals can help select proper temperatures to meet specific needs or create a desired ambience, generally dependent on illumination levels. Designers often coordinate lower chromaticity levels with lower illumination levels and vice versa. The most common light source in open offices is cool white fluorescent bulbs with a chromaticity of about 4100K. Growing in popularity are light bulbs with temperatures and illumination qualities very similar to natural daylight. These bulbs have temperatures above 3500.

The ability to *render colors* is a measure of how normal an object will appear under the artificial illumination source compared to the natural light of the sun. The International Commission on Illumination uses a scale of 1 to 100 to weigh the ability to render colors. The Color Rendering Index (CRI or R_a) is used to compare like chromaticity light sources to determine the most accurate color presentation qualities for a given situation. Experienced professionals combine light sources with interior color samples and work assignment types to provide atmospheres conducive to comfort, aesthetic appeal, and productivity.

Efficiency. Like all construction components, some light fixtures perform their function using fewer resources than others to produce a desired result. Careful design compares light sources of a particular quality and ability and incorporates the most cost effective long- and short-term solution.

Maintenance. An important concern in interior design is the cost of the designed elements over time. Maintenance can play a significant role in determining the cost effectiveness of particular structure. Light sources are often chosen for their ability to weather harsh environments, their resistance to dirt, their average bulb life, their ease of access to transformers and necessary equipment, and for their ability to serve other purposes such as air and power supply units. One method has been to build receptacles into their new light fixtures to allow the fixtures to be rotated and moved by simply unplugging and reconnecting them in a new configuration. This saves on hard wire costs, installation, and maintenance.

Indoor Air Quality and Control

The average American worker remains at home about 70 percent of the time and at work 16 to 20 percent of the time, or up to 90 percent of the time indoors. Such dependance on the interior environment for our life giving resources has led to several ergonomic concerns for their long-term effects on worker health. One great office health concern is Indoor Air Quality (IAQ). Interest in the air we are forced

to breath is increasing and the stakes for keeping it clean are growing higher everyday. The number of lawsuits being filed, the number and variety of responsible parties, and the award amounts are all growing. Federal legislation pending in congress will set rigid IAQ standards for building designers, owners, and operators. For example, the newly accepted American Disability Act (ADA), calls specific attention to breathing disorders and their handling. Tighter regulations are sure to follow.

Much media attention has been given to several environmentally hazardous materials used or conditions created in building construction. These materials include but are far from limited to, asbestos, formaldehyde, bioaerosols, radon gas, and volatile organic compounds (VOCs). Specific problems have been divided into two categories: Sick Building Syndrome (SBS) and Building-Related Illness (BRI). SBS is characterized when 20 percent of a building's occupants experience discomfort while in the facility and comfort upon exiting. BRI is defined by the contraction of a clinically defined sickness or infirmity from exposure to a built environment that lingers after the person leaves the building. For more discussion of interior environment health problems, see Chapter 4, "Health-Related Issues."

Indoor air quality and control is a complex issue involving multiple health hazards, multiple human comfort factors, several building types, and multiple system solutions. New building materials, methods, and energy conservation measures affect ventilation rates such that interior pollution levels and air character problems often exceed outdoors' levels. Technology has come up with several alternative means to combat these problems. Providing and controlling indoor air quality is important for the following reasons:

1. To enhance occupant health, safety, and welfare by minimizing short- and long-term health risks and to increase worker productivity
2. To provide a marketable facility. (Nobody is interested in a "tainted" or uncomfortable building.)
3. To conserve energy
4. To minimize facility and personnel costs
5. To minimize future legal liabilities.

Effects on the Office

Healthy air is imperative to pursuing the mission of an organization. Few components of the environment can contribute as greatly to costs of work loss as quickly or as easily as indoor air quality matters. Buildings with IAQ problems can result in various health and comfort complaints, while damaging building contents and the structural fabric itself. Occupant health problems reduce

productivity and increase absenteeism, costing building owners, tenants, and occupants valuable time and resources. Contaminants can increase the rate at which building components deteriorate, increasing operation, maintenance, and replacement costs. The following calculations show the "real people" costs associated with indoor air quality—ones that the office must account for in their daily operations and future plans.

Assume the following:

1. An average office space is 7,500 sq ft and contains 28 employees (BOMA).
2. Average maintenance costs are $8.31/SF-year of office space (BOMA).
3. Average salary/employee is $30,000/year.
4. Twenty percent of offices are affected by an IAQ problem.
5. The average loss of productivity due to IAQ is 10 percent.
6. The average office consists of twenty employees.

The value of lost productivity in $/year and $/day will be:

> $16,800/year = (28 employees) × (0.20 affected) × (0.10 productivity loss) × ($30,000/employee-year).
> $67.20/day for 5.6 employees "on the job," 10 percent less productive.
> $672 if all 5.6 employees miss work 1 day out of 250 days per year due to poor IAQ.

The cost of inefficient energy use, assuming $1/SF for outside air = $7,500 per year (for a typical office):

> $7,500 = 44 percent of the potential affected revenues/year ($16,800).
> $7,500 = $30/day (250 operational days/year) ~ 1/2 the productivity impact of affected workers on the job ($67.20) at the risk of encouraging a sick day of greater financial impact.

Definition of Acceptable IAQ

In simple terms, humans require relatively clean air (that is, pure common gases substantially devoid of hazardous gases, such as chlorine, or nonhazardous material, such as chalk dust) delivered under carefully controlled circumstances to operate at maximum efficiency and properly maintain their respiratory and other life systems. Poor air quality can be broken into two interrelated categories: pollution and environmental characteristics. Although there is no universal agreement on what constitutes acceptable indoor air quality, a widely recognized definition advocated by the World Health Organization is:

> The physical and chemical nature of indoor air, as delivered to the breathing zone of the building occupants, which produces a complete state of mental, physical, and social well-being of the occupants, not merely the absence of disease and infirmity. The physical and chemical nature of indoor air, as delivered to the breathing zone of the building occupants, which produces a complete state of mental, physical, and social well-being of the occupants, not merely the absence of disease and infirmity.

The chemical makeup of normal air is presented in Figure 22.

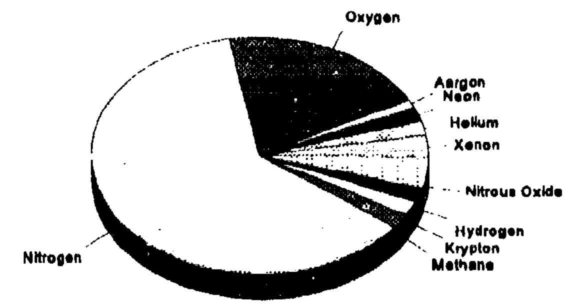


Figure 22. The chemical makeup of normal air.

Humans and Their Environment

To understand what makes people comfortable, one must understand how our body works. Design professionals have many years of training in understanding how humans react to certain environmental conditions. In short, every person's body is like a machine. Like any other heat engine, we consume fuel (food and oxygen) to generate power through a low temperature combustion process. Radiation and convection occur from our bodies if the temperature of our surrounding air is lower than our body temperature. If approaching or above this condition, the sweat glands expand and heat is expelled through evaporation. High temperature and high relative humidity render life increasingly uncomfortable.

At lower temperatures, the blood vessels near the surface of the skin tighten up, leaving the epidermis (upper layers of skin) dry and acting as an insulator. Shivering is a provision of nature to cause muscular activity and hence increase blood circulation.

Designers seek to accomodate six human factors that affect comfort in the interior atmosphere: air temperature, radiation, ventilation, relative humidity, and air movement.

Air Temperature. Most thermometers measure temperature but are not influenced by infrared (long-wave) radiation, because their glass envelopes are opaque to such wavelengths. The human body, however, may gain heat from radiant sources and requires air temperatures lower than body temperature to be comfortable. Research performed on factory workers in Great Britain doing light sedentary work established that air temperatures of 60 to 68 °F (16 to 20 °C) were regarded

Table 2. Acceptable ranges of temperature per relative humidity level during summer and winter.

Relative Humidity	Winter Temperature	Summer Temperature
30 percent	68.5° - 76.0 °F	74.0° - 80.0 °F
40 percent	68.5° - 75.5 °F	73.5° - 79.5 °F
50 percent	68.5° - 74.5 °F	73.0° - 79.0 °F
60 percent	68.5° - 74.0 °F	72.5° - 78.0 °F

as comfortable. Persons seated at rest required temperatures a few degrees higher, as did those accustomed to warmer climates. Table 2 summarizes acceptable temperature ranges as specified in ASHRAE Standard 44-1981.

Offices pose a particular challenge for system engineers. Most often this problem surfaces as a question of balance—providing thermal comfort for all people despite their differing job descriptions, dress, or location. Electronic equipment, people, and building elements such as windows, significantly influence the thermal dynamics of a given space. Often these elements are found in differing concentrations and locations leading to localized comfort problems. Blanket air handling systems, ones that evenly distribute air to all areas, are a thing of the past. Recent developments in air distribution technology provide infeeds to individual offices and workstations, permitting temperature control within the individual workspace. This helps to reduce the use of fans or electric heaters brought in by workers. Supplementary equipment of this nature can be very inefficient and can increase a facility's operational costs. In fact, small fans can actually add heat to the environment that they are intended to cool.

Radiation. Radiant heat uses building components around a hot air source to warm the air, for example the brick around a fireplace or the cover of a laser-printer. The effect of radiant heat source on the human body requires special attention. Unlike many heat sources, radiant energy composes only a small range of the total spectrum of wavelengths. Unrelieved monotony of a certain limited range of wavelengths, as from a gas fire or from an electronic heat source, can cause skin dryness and intense irritation. Design professionals recognize that the human system benefits from stimulation due to varying conditions.

Ventilation. Many air quality problems stem from an inability to effectively circulate a building's interior air, thus allowing potentially harmful materials to accumulate. The workspace plays host to many furniture, partition, and machinery items, most of which are subject to constant change and relocation throughout the life of the interior environment, resulting in poorly ventilated

workstations, offices, or conference rooms. Stagnant air can lead to dangerous concentrations of toxic air particulates and gases.

The technological solution to combating indoor air quality problems is using highly effective comfort and cleaning systems. HVAC systems are designed to take air from the outside, circulate it within the building, and then ultimately vent it to the atmosphere as exhaust, so they provide the mechanical means to increase airflow throughout the workplace. Originally, it was believed that 5 to 15 cu ft per minute (cfm) of fresh air was an adequate rate of ventilation, however, recent findings by the ASHRAE suggest that designers should use a standard of 20 cfm or greater for improved safety margins and wider tolerances for advanced filtration systems. Table 3 outlines the current ASHRAE ventilation requirements for many commercial applications.

The promotion of air quality has led several firms to increase their air handling systems as outlined above. Once considered a costly maneuver, upgrading to more efficient systems has been shown to actually save money. Research by Lawrence Berkeley Laboratories into the transition between lower ventilation rates to higher ventilation rates through office simulations yielded two important conclusions:

1. Dramatic increases in ventilation do *not* result in correspondingly dramatic increases in total annual energy and initial construction costs.
2. Buildings designed, constructed, commissioned, operated and maintained to optimize energy conservation and indoor air quality, can actually be less costly to operate than those not so planned (Eto 1988, Part 2).

Relative Humidity. Designers recognize that systems should be created and monitored to maintain the proper amount of airborne moisture in the interior environment. Optimal levels of humidity (units of water vapor per unit of normal air) minimize the effect of harmful environmental pollutants. In general, indoor humidity levels exceeding 60 percent can foster unsafe chemical interactions and provide stimulating growth environments for microscopic biological activity. High humidity in the summer months make people very uncomfortable and easily aggravated. The greatest impact of humidity, however, can be felt in the winter months. Most HVAC systems do a good job of regulating and removing summer humidity, but struggle to maintain moisture content in the winter. Heating systems, when operated for prolonged periods during the colder months, produce dry conditions that contribute to accelerated ozone reproduction and bacterial generation. When the indoor relative humidity drops, the incidence of absenteeism due to respiratory illness increases. Contact lens wearers may suffer discomfort and many other conditions begin to surface. The problem of employee

Table 3. Selected ventilation requirements (ASHRAE 62-1989).

Application	Location	Occupancy People/1000 sq ft	Cfm/Person	Cfm/ft²
Food & beverage service	Dining rooms, cafeteria, fast food kitchens	70	20	
		100	20	
		20	15	
Offices	Office space, reception area, conference rooms	7	20	
		60	15	
		50	20	
Public spaces	Smoking lounge, elevators	70	60	
		70	60	1.0
Retail stores, showrooms	Malls and arcades, smoking lounge, basement level shop, Street level shop	20		0.20
		70	60	
		30		0.30
		30		0.30
Sports and amusement	Spectator areas, game rooms, playing floors, dance clubs	150	15	
		70	25	
		30	20	
		100	25	
Theaters	Lobbies, auditoriums	150	20	
		150	15	
Education	Classroom, libraries, auditoriums	50	15	
		20	15	
		150	15	
Hotels, motels, resorts, dormitories	Bedrooms,			30 cfm/room
	lobbies,	30	15	30 cfm/room
	conference rooms, assembly areas	50	20	
		120	15	

absenteeism and discomfort decreases productivity and profit. An impact analysis of humidity levels is shown in Figure 23.

Devices for humidification can be added to most HVAC systems to moderate the interior conditions. The cost of such equipment is insignificant when one observes that the cost can be quickly recaptured by a productive and healthy labor force.

Air Movement. Effective air temperature depends on air velocity. The more air motion, the lower the effective temperature and relative humidity. An effective temperature of 70 °F with air speeds of 30 ft/min, makes the temperature drop 10 °F. Most offices are designed to sustain air movement speeds of 50 ft/min. People react favorably to such fluid movements. Localized turbulence may be

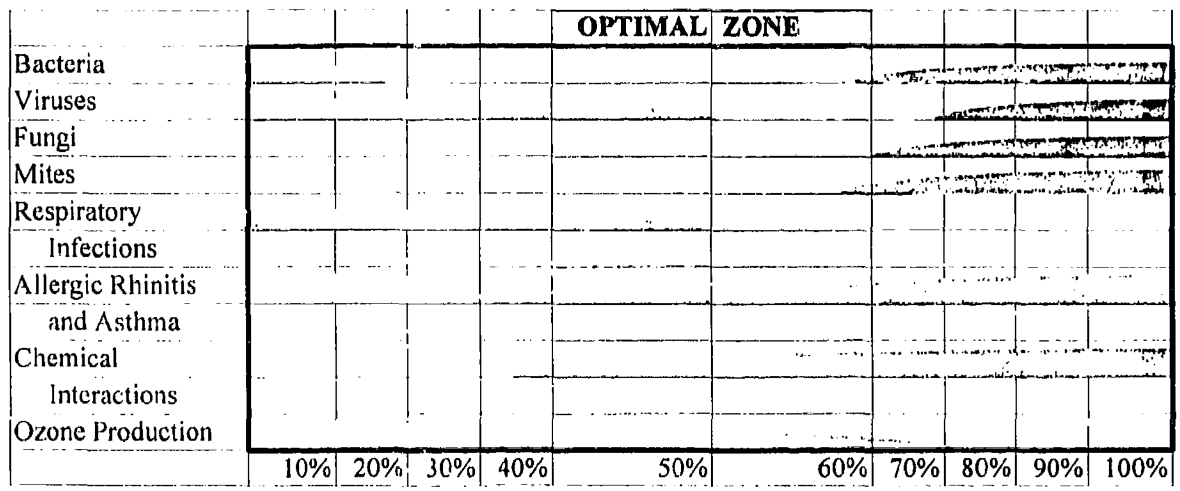


Figure 23. Impact of relative humidity on air quality.

experienced in areas with special office layouts. There is much greater probability of discomfort reported from drafts in interior environments with higher air speeds.

Designers experience particular difficulty when trying to introduce large quantities of cool air into a space while keeping velocities in the occupied region within acceptable limits. Often raising the relative humidity brings a higher effective temperature, which may permit a slightly higher air movement. It is easy to see that air movement comfort exists on a delicate balance. Common solutions to this problem include providing a large number of smaller supply and return air vehicles throughout the office.

Air Pollution

Air pollution is considered to be the primary concern for designers and product manufacturers today. Pollutants may be emitted from sources both inside and outside buildings. Inadequate ventilation is often cited as the primary cause of such problems, however; it is just one of many factors discussed above that aggravate people and create complaints. The National Institute for Occupational Safety and Health (NIOSH) has conducted research to determine the major causes of pollution in the interior environment. Their findings are briefly outlined below along with their percentage of occurrence in their studies. Twelve percent of their studies reveal unknown or inconsistent sources of pollution.

Building Materials Contamination (3 percent). Formaldehyde outgassing from urea-formaldehyde foam insulation, particle board, plywood, and certain glues and

adhesives were significant sources of building materials contamination. Other problem building materials included fibrous glass materials (asbestos), various organic solvents from glues and adhesives, and acetic acid used as a curing agent in silicone caulking.

Microbiological Contamination (5 percent). Microbial contaminants can result in a potentially serious condition known as hypersensitivity pneumonitis. This respiratory problem can be caused by bacteria, fungi, protozoa, and microbial products that may originate in ventilation system components. NIOSH investigations showed that a common source of microbial contamination was water damage to carpets or furnishings. Standing water in ventilation systems is also considered a potential threat.

Outside Contamination (11 percent). Contamination from sources outside the building include motor vehicle exhaust, boiler gases, and previously used interior air. These contaminant forms occur as a result of improperly located exhaust and intake vents or periodic changes in the wind conditions. Other forms of pollution include construction or renovation dust, asphalt vapors, and solvents. Gasoline fumes infiltrating a basement or sewer system via storage tanks are also common occurrences.

Inside Contamination (17 percent). Contamination generated by sources inside buildings are a major concern. Copying machines are a major contributor to this category. Theses systems include methyl alcohol from spirit duplicators, butyl methacrylate from signature machines, and ammonia and acetic acid from blueprint machines. Other inside contamination problems included improperly applied pesticides, bailer additives such as dethyl ethanolamine, improperly diluted cleaning agents such as rug shampoo, tobacco smoke of all kinds, and combustion of gases from cafeterias and laboratories. These items are in addition to the regular outgassing of carpet, furniture, and personal care products (Sliwinski et al., September 1991).

Inadequate Ventilation (52 percent). A major problem in air pollution is the accumulation of hazardous materials. As with most air quality factors, several facts explain this finding. Table 4 offers some sense of the elements that designers must consider when devising creative building solutions.

Solutions

Indoor air quality problems result from interactions between contaminant source, building site, building structure, activities within the building, mechanical equip-

Table 4. Design elements that influence building solutions.

Design Elements	Special Considerations
Reduced infiltration rate	Activities such as weather stripping, caulking, and window replacement benefit buildings by reducing operating costs, but may lead to other problems.
Use of variable air volume (VAV) systems	VAV systems respond to changes in zone loads by varying the amount of conditioned air supplied. Under conditions of reduced load, air supply to the zone is cut back and may lead to localized concentrations of hazardous materials.
Reduction in heating thermostat settings	Lower thermostat settings may cause air to cool more quickly than originally planned for in some heating systems. Condensation may occur in supply ducts when temperatures become too low. Standing water can breed molds and bacteria.
Increase in cooling thermostat settings	Increased humidity may result in some cooling types due to the lower delivered air temperature. Water concentrations may develop and contribute to molds and bacteria.
Increased building insulation and general componentry	Increased envelope insulation results in reduced loads through reductions in heat losses or gains. As technology increases, buildings require more parts that may contribute to the amount of hazardous particles present in a given office environment.

ment, climate, and occupants. Efforts to control indoor air contaminants change the relationships between these factors. There are many ways that people can intervene in these relationships to prevent or control indoor air contaminant problems. Control strategies can be categorized as: pollution source control, removal, modification, or substitution, time of use adjustment of a pollutant source, increased ventilation rates, air filtration and purification, improved distribution/integration systems, and education. Many mechanical systems exist to accomplish these individual tasks. It is beyond the scope of this document to discuss each system in detail, but the following paragraphs will generally present the goals of such equipment.

Improved Distribution/Integration Systems. The problems associated with indoor air characteristics are relatively easily solved by modern air distribution technologies. Designers have recognized that more personalized control of individual environments is important. Localized air supply is increasingly favorable to generalized comfort systems. Systems furniture units are being developed to have temperature controls and supply air systems integrated into wall panels and file units. Some task lights are available with built-in fans to

improve circulation and reduce concentrated heat loads from burning lamps. More thermostats and measurement devices are used to service smaller areas per unit.

One popular solution used to integrate furniture and comfort systems is the Personal Environment Module (PEM). This unit fits beneath a desk and gives each worker control of temperature, lighting, and sound masking while providing filtered supply air and ventilation. Similar systems are available in cluster designs to accommodate a group of offices.

Removal, Modification, or Substitution of Pollution Source. Source control focuses on controlling the levels of indoor pollutants by reducing emissions from various indoor materials and substances. Once the origin of a particular hazard has been determined, plans are made to spatially restrict or even prohibit its emissions from permeating the interior environment. For low level emissions, restrictions are placed on allowable quantities, locations, and treatments of specific materials. In general, source control is an appealing strategy with the greatest chance for curing a pollution problem.

It is very difficult, however, to limit what chemicals, products, or contaminants enter a building. Source control must often be used with other methods of control. People, furniture, paint, and automobiles tend to be the leading contaminant causes and carriers in closed environments and it is obviously impossible to limit these from interacting with a building. Examples of this method include restricting smoking, replacing dirty filters in HVAC systems, or removing water-soaked building materials (insulation, ceiling tiles).

Limiting Exposure to Pollution Source. If known pollutants or specific environmental characteristics must be endured, limiting the time of their existence can benefit an organization. For example, restricting access to certain building areas during the day (leaving doors locked or closed) may prevent the spread of poor quality indoor air. This is a process common to the construction industry, where certain cleaning solvents are applied only when there is little or no occupancy for a period of time, allowing ventilation systems to remove harmful concentrations.

Increased Ventilation Rates. As mentioned earlier, controlling hazardous material concentrations is an important part of winning the battle against unhealthy air. Improvements in existing air handling systems by supplying sufficient supply/return air vents, personal controls, and providing flexible systems that are easily changed to meet the evolving office floor plan are instrumental in ensuring the long-term success and happiness of building occupants.

Air Filtration and Purification. Complaints about air quality are often nonspecific and are often attributed to seasonal or outdoor allergies when in fact they may be the result of office borne microbiological particles. Most ventilation systems are unable to respond quickly to individual contaminants and suffice only to capture larger, more common air impurities. To best service worker air supplies, designers are moving towards local air filtration systems that continuously pass air through high performance filters and improve the ratio of supply to exiting air. It is becoming increasingly common to see these systems integrated with the PEM system previously mentioned.

Education. Programs that alert people to potentially dangerous material, or activities, and how to treat their occurrences should be developed in consultation with professional consultants. Committees should be formed to monitor, specify, act on, and solve indoor air quality concerns. Occupant relation programs should be developed to solve problems as they arise.

Telecommunications

Once considered to be the center of productivity—and a virtual "home away from home"—the role of the office has changed as dramatically as has communications technology. The increased importance of family, the understanding of personal comfort and its direct link to greater work output and quality, and the general societal movement toward more economical business systems has changed the way that we will conduct our business affairs forever. Technology has evolved to the point where the office is now more commonly recognized as any place where business is transacted, rather than a specific building, room, or workstation. Electronic technology allows one to be connected with any person, anywhere in the world, at any time. The office is now an airplane, a television, or home computer remotely controlling a file server in the neighboring town.

The futurist Alvin Toffler has forecast the emergence of the "electronic cottage" as a new way that work and play will be organized in the future (Toffler 1980). The advancement of personal computers and facsimile machines make it possible for people to work at home instead of traveling to offices that may be 30 or more miles away. As seen by Toffler, the electronic cottage revolution will reduce auto pollution, bring the family closer together as a work unit, and foster more home-centered entertainment and activities.

Telecommunication systems are paving the way for these kinds of transformations. In fact, telecommunications may soon be the law. Currently, two acts are under

consideration for federal legislation, making it necessary for employers to develop strategies to let staff work at home. The most widely recognized plan encouraging telecommunications is found in the amendments to the Clean Air Act passed in 1990, effective November 1993. These amendments stipulate that employers in certain high-pollution metropolitan areas must develop plans to reduce the number of commuting employees. The Family and Medical Leave act was activated early in the summer of 1993. This act entitles employees to 12 weeks of unpaid, job-protected leave each year for specified family and medical emergencies. Each act opens the door for companies to develop telecommuting plans that let employees continue their work at home. Even if you are not legally motivated to develop telecommunication plans, there are several sound business benefits for planning for their increased implementation. Reasons include:

- Fewer staff support requirements—fewer permanent in-house employees require less support
- Lower office costs—electronic communications save mailing costs, time, and personnel hours.
- Environmental conscientiousness—telecommunications reduce office paper flow, transportation-related fuel consumption, and traffic-related emissions.
- Time savings—information transfer can be nearly instantaneous, and electronic data transfer can eliminate many employee information-processing tasks.

Telecommunications Defined

Telecommunication systems are broadly defined as all devices and techniques used to transmit signals, signs, writing, images, sounds, or data of any nature by radio, wire, or any other electromagnetic medium. Popular end-user components include personal computers, facsimile machines, telephones, and scanners. These components are linked to local area networks (LANs), wide area networks (WANs), bulletin board systems (BBS), and electronic mail (e-mail) systems. The advent of this technology affects office design in several ways.

Affect on the Interior Environment

Any corporation that expects to survive must learn to exploit the advances in technology. Facility design professionals provide for this opportunity for survival by creating intelligent buildings. An intelligent building is not necessarily gadget-oriented, but is designed to suit the absolute needs of the occupants. It must

easily and economically accommodate change, have its basic elements integrated into a synergistic whole and, above all, be cost effective.

Design professionals bring together the myriad of components in a building's structure that meet the goals of a company's internal and external communication systems, facility automation systems, and data-processing systems. Several major trends will shape both the concept, design emphasis, and reality of the intelligent building in years to come. The following sections describe some of these trends.

Trend 1: Linking People Together. Before 1980, most commercial building designers did not consider including data communication systems in projects unless it was known that extensive computer use was going to occur on a specific site. During this time period, computer systems were usually large mainframes that required extensive design and construction planning. They used proprietary wiring and hard-connected dumb terminals that posed no major problems in office automation change, providing growth was slow. However, the advent of the personal computer has brought increasingly more powerful computing resources to individual workstations and initiated the high pace office electronics explosion that we see today. The need for efficient data-sharing technology developed out of the frustration of manually swapping disks, waiting in line at a dedicated printer, and wasting valuable time and money to paper publish all forms of written communication.

LANs were introduced and gained immediate popularity. Their presence has grown to include nearly all offices designed today. Unfortunately, so has the amount of wire used to connect such systems. Technicians have poked cabling through floors, ceilings, walls, holes in desks, and under the carpet. These cables integrate other computers and provide interconnection opportunities between mainframes and minicomputers and wide area networks.

The net impact on the interior design professional has been an increased pressure to provide flexibility in the working environment. Building design has been complicated by the intense demand for forecasting the future needs of a company and providing the ability to grow into these needs without compromising the abilities, appearance, or quality of current facilities. For example, industry specialists predict a 35 to 40 percent growth in local area network purchases over the next 5 years. Figure 24 shows the past and predicted growth of the number of personal computers connected to LANs.

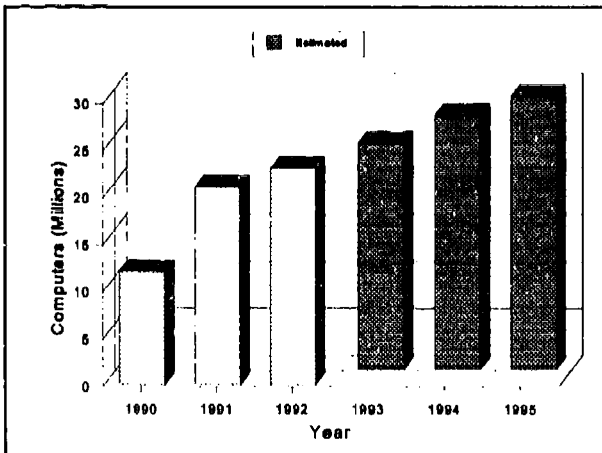


Figure 24. Computer use.

To accommodate this increase, designers must prepare for a swarm of specialized equipment such as routers, file servers, concentrators, multiplexors, and intelligence hubs. Those concentrating in the building sciences must prepare for high churn rates, personnel turnover, and machine relocation. A delicate balance must be struck to provide for new machinery while allowing for the existing necessities of the working environment.

Trend 2: Following the Links. One common complaint of computer systems administrators is that, in the business (of telecommunications) today, managers want to exploit the computer's capabilities, but seldom consider the cabling system. A system with over 1000 outlets may command 40 to 50 percent of a network manager's time to simply trace circuits and wiring runs rather than solving actual system problems. This can be very costly as even 10 percent of a network director's time can add up to over $20,000 per year.

Interior architects are key to reducing long-term expenses associated with telecommunications. One of the designer's most important tasks is to coordinate efforts of other trades. "Forty-six percent of network managers at Interop 1992 cite logical configuration management, physical configuration management, and fault isolation as the critical network management requirements." To this end, designers work closely with electronic specialists to develop efficient wire distribution systems that allow easy access and permit simple traceability.

Trend 3: Internal Building with the Links. At the foundation of an intelligent building capable of communicating with the outside world is a highly structured internal wiring system. Internal wiring systems not only connect other computers, but also link building systems and utilities. Centralized control and monitoring of thermostats, smoke detectors, security, lighting, and pollution levels are critical to cost effective building management in the future. This can be done using the technological capabilities of modern telecommunication systems.

One method of integrating a building with telecommunications is called *structured wiring*. The Telecommunications Industry Association (TIA) has published standards that define the characteristics of such systems. Structured wire systems combine differing wire platforms and use into open data distribution

systems that permit interconnection and control of all electromagnetic machinery. Building designers, therefore, recognize that successful facilities are ones planned and constructed for completely integrated building elements. Traditional design that adds building systems piecemeal to a set of floor plans generally proceed at the expense of the occupant or building owner.

In short, advances in telecommunication technology between geographic locations have prompted the improvement and interconnection of elements within buildings Interior designers recognize the importance of such advancements and work with their capabilities to provide cost-effective work environments.

4 Health-Related Issues

Interior design reflects, in part, an organization's efforts to create a healthy office environment where people are comfortable, productive, and at ease. Significant advancements in healthy office environments have contributed to increased productivity, decreased absenteeism, and a decrease in health care costs.

A growing incidence of employee sick leave, medical claims, and law suits is related to the health and safety of office environments. Interior design is critical in providing solutions to all these problems. Proper application of design principles can provide a healthy office environment, and can increase worker satisfaction, productivity, and workspace functionality. This section explores the value of interior design as it relates to worker health and the office environment.

The value created by interior design will be explored by looking at the causes, effects, and solutions to common health-related issues in the office environment:

1. Pain in muscles, tendons, and lower back
2. Sick Building Syndrome and Building-Related Illness
3. Eye problems
4. Stress.

Pain in Muscles, Tendons, and Lower Back

Health-related problems among office workers have become the subject of recent concern because of the rapid growth of white collar jobs and the time spent indoors. Work-related illnesses cost companies hundreds of thousands of dollars a year by decreased productivity and increased absenteeism. Interior design can address many of the problems, symptoms, causes, and effects.

Repetitive strain injury (RSI), repeated trauma incidence (RTI), and cumulative trauma disorder (CTD) are all terms for a range of conditions characterized by pain in muscles, tendons, and other soft tissues—with or without obvious physical causes. The various health problems include but are not limited to tendinitis, tenosynovitis of the upper limb, lateral epicondylitis, carpal tunnel syndrome, and neurovascular problems. Figure 25 shows the Bureau of Labor Statistics

estimates of repeated trauma incidence rates from 1978 to 1989 in the United States.

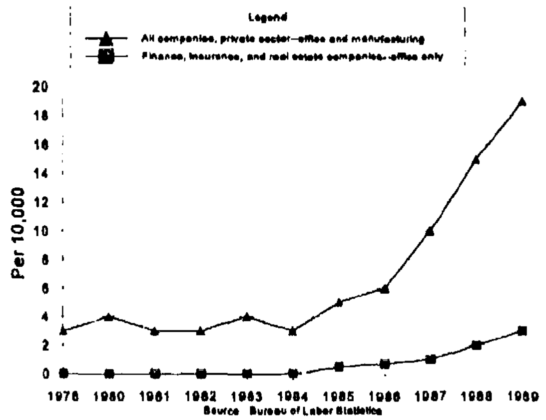


Figure 25. Repeated trauma incidence rates.

Common RSI Conditions

Tendonitis. This is the swelling of the tendon due to frequent tension of the muscle and the tendons. This problem can cause permanent damage. Keyboard operators who adopt awkward postures at the display screen may find that static muscle loading leads to this disorder. A common shoulder tendon disorder is called *rotator cuff tendinitis*. The rotator cuff includes four tendons that fuse over the joint to provide stability and mobility for the shoulder. The tendons rotate the arm inward and outward, and help in moving the arm away from the side.

Tenosynovitis of the Upper Limb. This is the swelling of a tendon due to repeated strain or trauma. This tendon injury affects the forearm or wrist that may become swollen and painful. A symptom of tenosynovitis is persistent pain in the forearm and wrist.

Lateral Epicondylitis (Tennis Elbow). When the tendons in the lower arm become strained or overused, they become irritated and inflamed, and cause pain in these tendons from the elbow and along the forearm. The tendon involved in extending wrists and supinating hands seems to be most vulnerable to this condition.

Carpal Tunnel Syndrome (CTS). The carpal tunnel is a short passage in the wrist surrounded by bones and a ligament. The median nerve, tendons that flex the fingers, and blood vessels pass through this tunnel. Irritated tendons may swell and compress the nerve, since the walls of the tunnel are solid and will not expand to accommodate swelling. This compression results in CTS. Symptoms of CTS include pain, tingling and numbness in the thumb, index, middle, and ring fingers; swollen fingers and impaired grasping ability are possible symptoms (Figure 26).

Arm and Shoulder Problems (Neurovascular Problems). In the elbow and shoulder joints, the extensor muscles, which attach at the elbow, control movement of the wrist and hand. When strained or over-used, the tendons become irritated and radiate pain from the elbow down the forearm. This problem may also involve both the nerves and nearby blood vessels. Certain activities or postures can slow

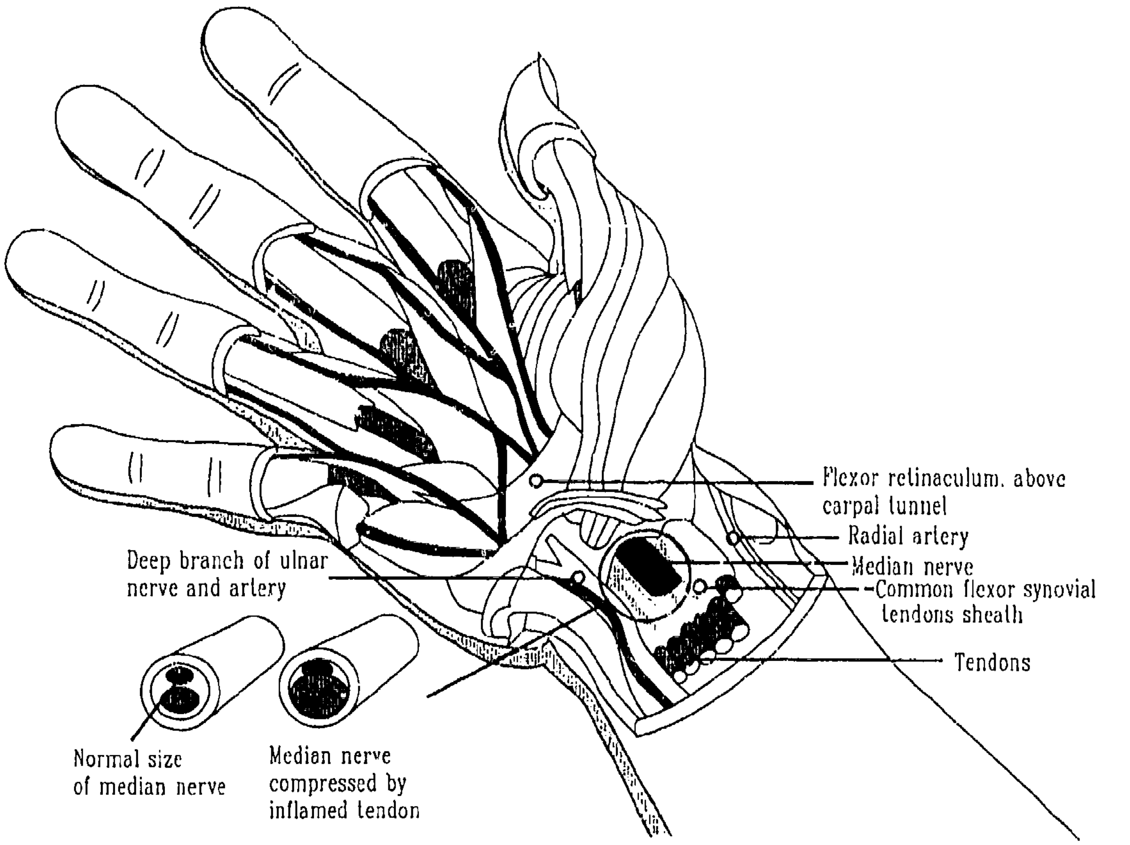


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Figure 26. Physical cause of carpal tunnel syndrome.

circulation by causing the nerves to be compressed. If this happens, nearby muscles, tendons and ligaments do not get oxygen and nutrients. Symptoms are similar to those of carpal tunnel syndrome.

Causes of RSI

- High rates of motion repetition (typing, stapling, stamping, dialing)
- Sustained or constrained postures
- Forceful movements
- Repeated wrist flexion or extension
- Rapid wrist rotation
- Pressure with palm
- Work practices
- Finger pinching.

Effects of RSI

Increased Healthcare Costs. One multinational corporation has estimated that the cost of treating a single case of RSI can range from $70,000 to $120,000 (Sauter 1987, p 2-5). In 1984, the Academy of Orthopedic Surgeons estimated that $27 billion was spent on lost wages and medical care by this work-related injury.

Loss of Productivity. "One severe case of CTS can cost $100,000 in medical and administrative expenses and lost productivity." Blue Cross and Blue Shield of California, a heavily computerized insurance firm spent an average of $20,000 on each of 30 RSI claims in 1990.

This is further substantiated by the Wall Street Journal, which showed the 1990 spread of RSI in such industries as meat packing, poultry processing, autos and supermarkets—an eightfold increase from 1982. According to the Bureau of Labor Statistics, RSI accounted for 56 percent of all workplace illness in 1992, compared with just 21 percent in 1982 (Llin 1992, 3).

Possible Solutions to RSI Through Interior Design

The purpose of interior design in this section is to create working environments that enhance the user's quality of life and operational potential. This is done through a detailed analysis of the user's functional, operational, and task requirements. The resulting designs would be carefully coordinated with the overall building design and be managed during the construction of the building, and the procurement and installation of the furnishings.

Interior designers will make sure that properly designed keyboards are specified to reduce the risk of carpal tunnel syndrome. The thickness and the adjustability of the keyboard and the angle of the key tops themselves affect the movements a user must make (Miller, 11). Proper wrist support will increase comfort and allow the wrist to remain in a neutral position during keying. Provide foot support for short individuals. Designers will make sure that nontoxic products and building products are specified.

If the work environment incorporates ergonomic factors, both productivity and safety may improve. It is important to analyze existing ergonomic conditions and solve any ergonomic-related problems (see Chapter 2.)

A reduction in productivity can result from a misfit between furniture and task requirements. For example, chairs should provide optimal postural conditions, be

adjustable. and the user should be comfortable and well supported. Properly designed space will match furniture and task requirement together.

Back Pain and Interior Design

Back pain is a common and a widespread problem. A fourfold increase in the working days lost to back pain in the last 15 years has caused enormous direct and indirect costs (Miller, 6-7). The major causes of back pain include:

- Physical damage to other tissues and spinal nerves from specific disease
- Acute anxiety or depression
- Prolonged sitting
- Working conditions
- Inappropriate use of chairs and use of inappropriate chairs.

The costs of treating back pain are very similar to treating RSI. According to one estimate, the cost of treating one back injury case can run as high as $100,000 (Sauter 1987). According to the National Safety Council, the average cost of treating lower-back injury is about $6,825—and if the injury requires surgery, the cost can jump to $60,000 (Fernberg 1990, p 49).

As discussed above for RSI, interior designers can apply principles of workstation design, ergonomics, and furniture specification to help prevent many common causes of work-related back pain.

Sick Building Syndrome and Building-Related Illness

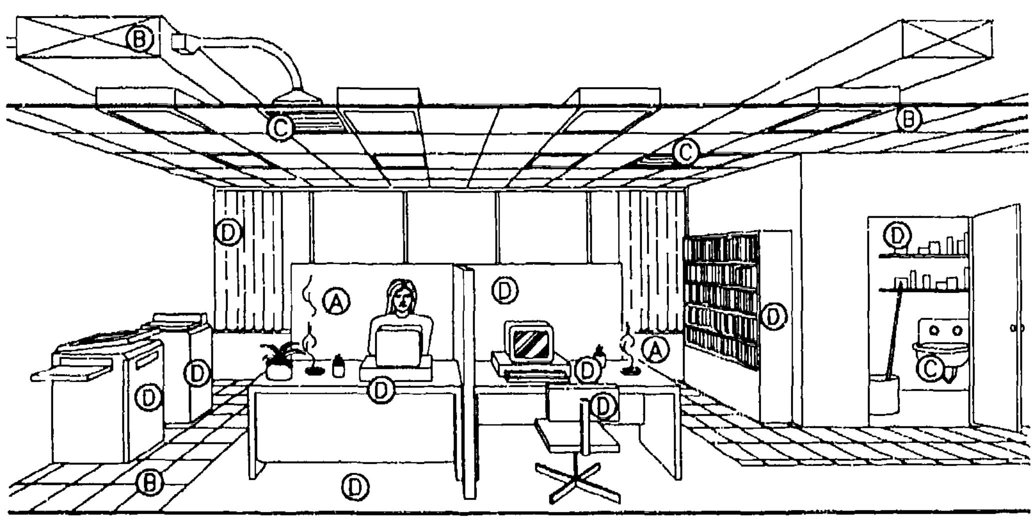
When more than 20 percent of a building's occupants complain of discomfort while in a facility, but experience relief soon after leaving the facility, the problem is suspected to be Sick Building Syndrome (SBS). When an occupant's exposure to indoor contaminants causes a clinically defined illness or infirmity that lingers long after the person leaves the building, the sickness is called Building-Related Illness (BRI). An important distinction between SBS and BRI is that SBS is not tied to specific contaminants but BRI is traced to a specific source. The BRI group of illnesses can be directly attributed to something within the building. BRI includes asthma, skin problems, allergy, and legionnaire's disease.

Common Causes of SBS and BRI

Studies show that SBS results from indoor air pollution. An indoor environment study by Healthy Buildings International, Inc. showed that SBS results from HVAC operating faults and poor maintenance, basic design errors, functional changes that impact heat loads, inadequate ventilation, poor air distribution, inefficient filtration, and contaminated ductwork (Silberman 1993, pp 2-3).

A dirty air conditioning system can serve as an incubator for bacteria and fungi and can prevent air from circulating. Chases—especially those that share their space with air handling units—can become collection points for dust and grime. Plenum spaces may collect water and other liquids, allowing buildup of gases and fumes such as carbon monoxide, carbon dioxide, and formaldehyde. Other gases that pollute interior environments may include formaldehyde, ozone, and radon. Figures 27 and 28 show common workplace contaminants and their sources.

Formaldehyde. Formaldehyde is found in building products such as paneling, particleboard and plywood, urea-formaldehyde insulation, and fabrics. Furniture is another source; materials used in carpeting and panels may contain formaldehyde. People exposed to even very low concentrations of formaldehyde gases can suffer skin, respiratory, throat, and eye irritation. Formaldehyde is recognized as a central nervous system depressant and potential carcinogen.



A - Cigarette, cigar, and pipe smoke (can migrate beyond smoking areas)
B - Asbestos (ceiling and floor tiles, heating system, and acoustic insulation)
C - Microbes (air conditioners, humidifiers, washrooms, ventilation pipes and ducts)
D - VOCs (felt tip markers, copy machines, paint, solvents, cleaning compounds, furniture partitions, carpets and drapes)

Figure 27. Workplace contaminants.

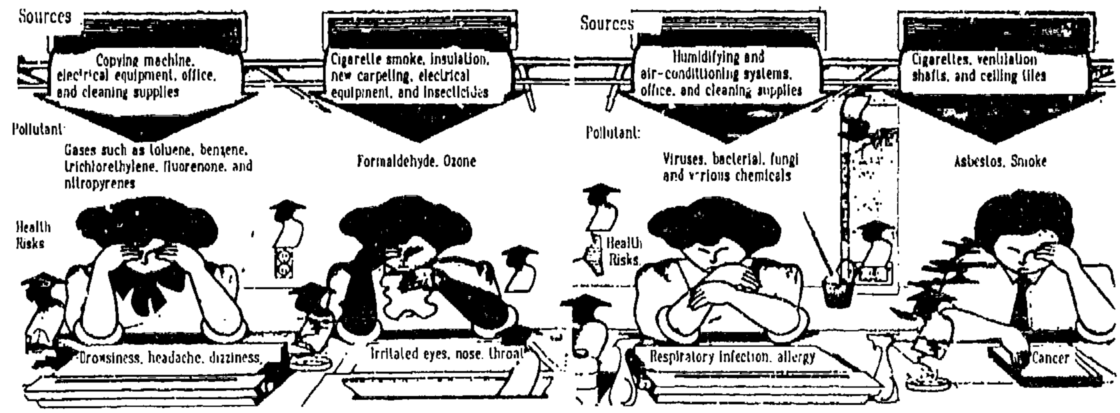


Figure 28. Prime office pollutants and possible effects.

In 1992, the U.S. Occupational Safety and Health Administration (OSHA) set limits on the level of formaldehyde to which people can be exposed in the workplace. Any product that has the potential to produce formaldehyde concentrations above 0.1 parts per million must carry labels to that effect. Only products that meet the strictest OSHA formaldehyde standards and have independent or objective test data to prove it should not have labels.

Ozone-Depleting Substances (ODS). Sources of ODS include a variety of common chemicals such as aerosol sprays, refrigerators, fabrics, foams, and adhesives. In rare cases, ozone can be emitted in the interior from defective electrical equipment and lighting systems.

The U.S. Environmental Protection Agency (USEPA) defines two classes of ODS: Class I includes chlorofluorocarbons (CFCs) and methyl chloroform; Class II covers hydrochlorofluorocarbons (HCFCs). Class II ODSs may deplete ozone less than Class I ODSs, but the use of both classes is regulated. Recent USEPA rules implementing the Clean Air Act Amendment of 1990 tighten restrictions on ODS use. Beginning 15 May 1993, products that contain or are manufactured using any Class I ODS must carry a label to that effect. In January 1994, the Clean Air Act calls for an outright ban on the sale of specified products made with any Class I or Class II ODS, including some foams used to make furniture.

Radon. This colorless, radioactive gas can seep into a building through the basement's soil and water. This is one of the most hazardous and prevalent of the indoor air contaminants. It usually does not present a problem in commercial buildings more than two stories because it disperses evenly (Clark 1990, 45). A study of radon in low-rise school buildings, potentially similar to typical administration buildings on Army installations, suggest that HVAC system operation can play an important role in determining indoor radon concentration. The study found that improper operation of an HVAC system could create a negative pressure within a building, resulting in radon migration into the building from the soil (*Building Air Quality* 1991, 18).

Volatile Organic Compounds (VOCs). Sources of VOCs include cleaning agents, paints, fabrics, solvents in adhesives, tobacco smoke, pesticides, photocopying materials, refrigerants, and some building materials. Figure 30 compares VOC emissions from a series of typical interior products.

The USEPA has developed a technology that permits emissions from products to be accurately measured. Emission factors are typically expressed as mg/m^2 *hrs, which describes the amount of chemical emitted per square meter of exposed product surface, over a specific period (USEPA 1991).

Particulates. Sources of particulates include a broad range of materials that may be found as solid particles or liquid droplets suspended in indoor air. These particulates include but are not limited to: tobacco smoke, asbestos, pollen, mold spores, and dust. For example, it is estimated that 1,000 people a day will die prematurely from heart disease and lung cancer due to environmental tobacco smoke. An estimated 5000 of the deaths per year will be due to involuntary smoke inhalation. Major health effects attributed to particulate exposure include respiratory impairment, aggravation of existing respiratory and cardiovascular disease, and allergic reactions.

Microorganisms. Contaminants including bacteria, viruses, fungi, and microscopic inorganic materials are associated with improperly maintained HVAC systems and moist building materials. Major health effects attributed to microorganisms include infectious disease and allergic reactions.

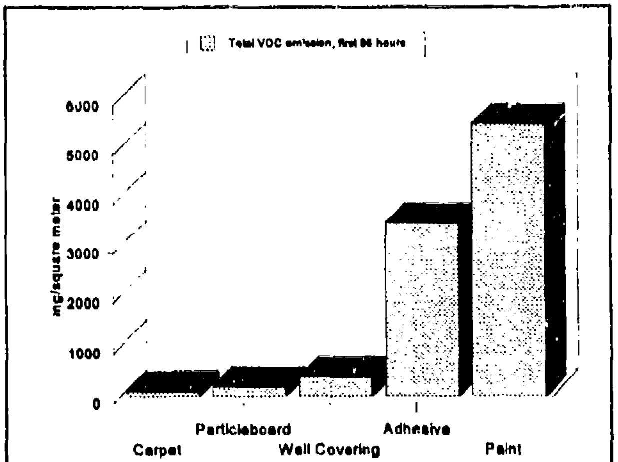


Figure 29. Relative product performance.

Effects of SBS and BRI

Increased Absenteeism. Much of the absenteeism is for doctor's appointments for treatments. Absenteeism poses a multiple threat to the employer; decreased productivity, decreased morale, increased employee turnover, and increased employee medical costs.

A survey of 1,000 workers conducted by Harris Research ("Office Buildings Make Workers Sick" 1992, p 8) showed that more than 62 percent reported that they experience SBS-type symptoms commonly at work. Twenty-six percent said that they take a day or more off from work each year due to these ailments. Fifty-eight percent said that they believe their work rate could improve in an office environment with cleaner and fresher air.

Increase in Workers' Compensation Claims. An Indoor Air Pollution Report showed that poor IAQ costs $6.4 billion per year in medical expenses and lost productivity. (Indoor Pollution Law Report 1990, 2-5). As hospital visits increase with no permanent relief, employees file claims, usually out of sheer frustration.

Increased Litigation. Figure 31 shows that the number of cases related to IAQ is rising (IFMA 92, 247), and the amount of the damages incurred is increasing at an alarming rate.

Possible Approaches to IAQ Through Interior Design

The importance of interior design in this regard is to create working environments that are free of pollutants and poor indoor air quality. This is done through a detailed analysis of the user's function, HVAC operation, pollutant control, and health requirements. The resulting designs must be carefully coordinated with the overall building design, mechanical design, and products to be used.

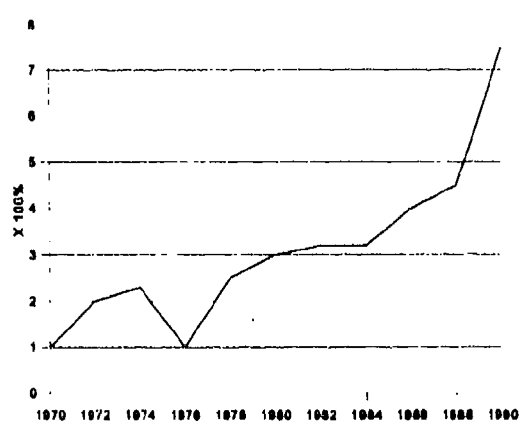


Figure 30. Increase in cases filed.

Heating, Ventilating, and Air Conditioning (HVAC) Design. If a facility is to deliver acceptable IAQ (and remain productive), it must start with a design that adequately accounts for the number and distribution of people who will use the facility (Figure 32). Design professionals consider the equipment and the processes that personnel use to do their

work. Further design considerations suggest breaking up building HVAC systems to help distribute air. Also, the HVAC system must comply with the minimum criteria set forth in ASHRAE Standard 62-1989.

Source Control. This strategy focuses on controlling indoor pollutants by reducing emissions from various indoor materials and furnishings. The interior designer should specify low-emissions products, both for use in new construction and renovation.

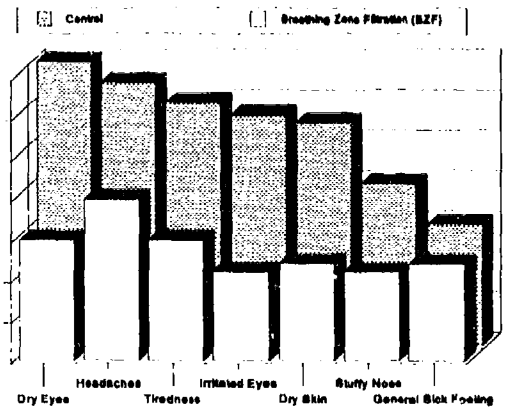


Figure 31. Effects of BZF system on SBS.

Eye Problems

Eye problems are a common health complaint reported by people who use computers for much of their work. The most common complaints expressed by the office workers are eyestrain, burning of eyes, blurred vision, irritated eyes, and headaches.

Causes of Eye Problems

Too Much Contrast. Excessive contrast between computer screen, hardcopy documents, windows, and lights may strain the eye. This large brightness contrast in the visual field can cause adaptation to the brightness source. If the bright source is in the background, the eyes may adjust to the background and cause difficulty in reading the display. Other studies on visual discomfort found excessive luminance contrast ratios on the visual field (Stammerjohn et al. 1981; Coe et al. 1980).

Overwork of Eyes. Eye fatigue occurs when the demands of the visual task exceed the visual abilities of the individual.

Reflections. Computer monitor screens reflect light from windows, lighting fixtures, and other bright surfaces. When reflections diminish the contrast between characters and background, visual quality drops and reading is difficult. This condition may cause visual problems.

Uncorrected or Improperly Corrected Vision. Visual impairment can trigger some of the cited problems. Some people fail to wear eyeglasses or contact lenses they need; others may need new prescriptions. Those with uncorrected eye problems can compound their problems by working at a visually demanding tasks.

Job Task. Many office workers experience symptoms because of the mismatch between the demands of the task and the distribution of visual abilities in the population (Sheedy 1990, 17). Jobs that require fixed-distance focusing (e.g., reading and drafting), especially at a long range, may tire eye muscles noticeably.

Poor Lighting. Good lighting consists of equal luminaries; recommended lighting levels for VDT use are low. (Chapter 2 gives more lighting information.)

Glare. Excessive glare and poor image quality of printed material may cause problems. Glare, often (incorrectly) perceived as "too much light," is caused by both amount and direction of light (Figure 32). Misdirected light from excessively bright luminaries or windows is often improperly shielded from peripheral view.

Possible Solutions for Eye Problems Through Interior Design

The importance of interior design in this section is to create working environments free from visual dilemma. This is done through a detailed analysis of the user's function, visual requirements, and lighting quality. The resulting designs must be carefully coordinated with the overall building design, lighting design, and equipment to be used. Interior designers will also do the following to enhance the value added to interior design:

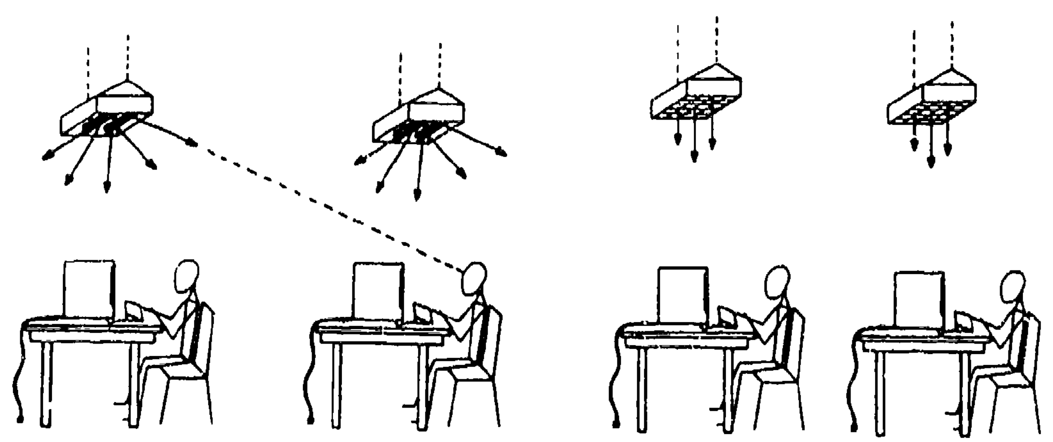


Figure 32. Excessive brightness caused by direction of light.

Glare Reduction. Sources of glare in the user's field of vision would be removed, either by repositioning the user's workstation, or by shielding the source. Direct glare from sources of light, such as windows, openings, transparent or translucent walls, and brightly colored fixtures or wall would be avoided in office design (Robens Institute, 15-16).

Reflection Reduction. Workers often are unaware of the reflections; it is suggested that they turn off their VDT to look for reflections. Then they should turn on the VDT and note whether reflections are visible and interfere with the work presented on the screen. Reflection can be reduced by moving or reorienting the workstation, or by tilting the screen.

Proper Lighting Design. Distracting light should not appear within the visual field of a user during his working activities. The line from eye to light source must have an angle more than 30 degrees to the horizontal plane. If a smaller angle cannot be avoided (e.g., in large offices) then the lamps must be shaded more effectively.

Proper Workstation Design. Proper ergonomic design and adjustment of VDT workstation and its environment can decrease the visual demands of the task and result in a more comfortable visual environment (Sheedy 1990, 17). The concept of the VDT triangle which is based on the interaction of three work components: the monitor, keyboard, and document can reduce eye strain. All three of these components should be placed at equal focal lengths, and require a minimal amount of effort with the user to interface among the three. By providing the minimum amount of distance between the three, the amount of eye motion and also the amount of refocusing are reduced.

Specification of computer monitors may also fall within the interior designer's responsibilities. The characters on a monitor screen are formed by a matrix of dots (pixels). Generally a denser dot matrix comprising each character and a better-defined pixel yield better resolution. The ANSI standard recommends a minimum dot matrix of 5x7, but a denser matrix is preferred. Better VDT resolution enhances worker performance and visual comfort (Sheedy, 23).

Stress

Stress is a common problem in office environments, but it is considered a psychosocial problem because it centers on people's psychological reactions in an

office environment. Nevertheless, stress, caused by internal or external factors, will have a significant impact on the human body. For instance, the risks of musculoskeletal disorders, given the same physical load, will be higher for a person working under mental strain. Quite often, other health problems such as musculoskeletal tension may be a manifestation of stress. Other indications include but are not limited to anxiety, headaches, sleeplessness, aggression, depression, irritability, confusion, and fatigue.

Causes of Stress in Office Environments

Fixed Tasks. A job without flexibility in how a task is accomplished can cause stress. Cohen et al. (1982) compared two kinds of VDT jobs for stress, and found rigid work procedures to be a common cause for stress.

Lack of Control. Most office work involves use of a computer. Computers often do not allow people to exercise control over the manner, order, or pace of their work. Tasks must be performed in the prescribed ways, in the prescribed order, and at a pace dictated by the system's response time.

Repetitive Tasks. According to Stammerjohn et al. (1981), repetition is among the most important factors in job stress. Repetitive jobs may create boredom and cause health problems.

Pressures for Performance. Constant pressure to meet a job's deadline or to achieve high performance may cause stress (Cohen, et al. 1982).

Health and Safety Concerns. Increased use of automation in office environments has created many concerns over adverse health effects associated with VDT use. Employees are concerned about good posture, correct hand and wrist placement, and visual difficulties in the office environments, which all cause stress.

Heavy Workloads. Most organizations use computers to increase productivity and to produce high quality products. When employees are expected to perform at maximum rates for long periods of time, stress can occur.

Posture. For workers within an office environment, there is likely to be much more variability in postural causes of stress. Good posture is essential for employees' comfort and well-being. Differences in workstation design, personal work style, and personal physical characteristics may lead to variability in actual postural stresses. Sitting awkwardly may create poor posture and muscle strain.

Effects of Stress

Effects of stress are the same as those in other health-related issues. In the United States, for example, cardiovascular diseases, which are widely held to be stress-related, accounted for $11 billion dollars of lost output to industry during 1981 (Dainoff 1986, 150). Figure 33 shows how working with a computer affects an employee's noradrenaline levels compared to levels in the same office environment while doing things at leisure (Smith and Salvendy, 1993, p 747). Noradrenaline is a hormone secreted by the adrenal gland that dilates blood vessels during shock, anxiety, depression, irritability, confusion, and fatigue.

Stress and Interior Design

Most of the design-related problems encountered in the office environment can cause stress. Solutions to the problems, however, cannot be accomplished by independently addressing the equipment and environment. Possible design solutions include the use of alternate workstation designs that consider individual differences. Such an approach will reduce the design-related stress-causing problems in the office environment.

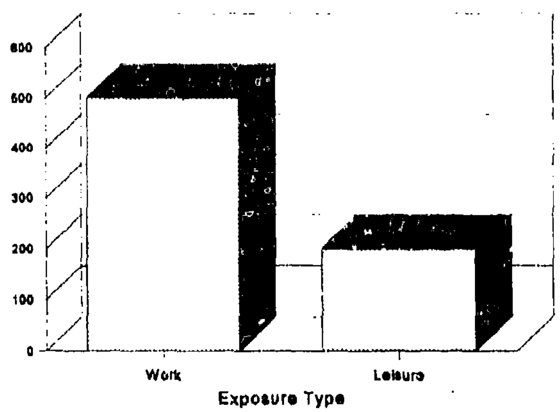


Figure 33. Measured levels of noradrenaline during work and leisure.

5 Design Programming Issues and Tools

As shown earlier in Figure ES1, the office environment is a complex system of physical environment, individual, organizational, and work-task characteristics. Previous sections have discussed some important issues of space, furnishings, and technology that go into the total office system. That the office environment can have a serious impact upon major outcomes such as health, worker satisfaction, and performance has become increasingly apparent in the popular press, as well as in research studies around the world. However, specific information about the relationships between individual characteristics of the office environment and outcomes of health, satisfaction, and performance is only beginning to build into a knowledge-base to guide those who make critical decisions about the design and management of workplaces.

Designers have always been charged with integrating the whole building environmental system. Now they are increasingly interested in broadening that view by seeing the office through the eyes of the individuals in the environment. The direct users of an environment know the ways that the workplace environment can hinder or help (either directly or indirectly) their job performance. An important portion of this information must come from the users themselves. The activities that help the designer learn about workers' use and perception of the office environment are programming and post occupancy evaluation. USACERL has the experience and tools to facilitate these activities.

There are two critical times to involve users in facility planning and management and several methods that may be used to gather the information. A case study will illustrate the use of a tool to measure the impact of the interior environment on the user.

Evaluating workplaces effectiveness

Good design always includes a set of predictions about future conditions and events. For example, an architect or interior designer selects furnishings based on the prediction that certain activities will occur, or includes partitions in an office based on the prediction that privacy will be sought. However, designers rarely have the time or tools needed to measure the success of their predictions.

This is unfortunate because if designers were able to measure success, they would then be able to more accurately predict how users will respond to a given environment. That in turn would allow them to use their design time more efficiently and more economically. If architects and interior designers were able to predict how users will experience a future environment, they would reduce the need for post construction changes. *Getting the design right the first time will save the client aggravation and dollars.*

Workplace data gathering

The first time to ask how things are working is during the design programming phase of a specific facility. Obtaining information from users of the environment, at this time, can help to determine what design issues are most important to them in doing their job. Usually two kinds of information will be of interest: (1) descriptive information about equipment, space, and activities, and (2) perceptual information about comfort, privacy, and other workplace experiences. Examining the responses of those individuals in an existing environment can define the design priorities from the users' perspective. This information can be very important in setting the priorities for the designer as decisions are made about future modifications or future facilities.

The second time to ask "how things are working" is after a designed environment has been occupied. This is an opportunity to test predictions (both implicit and explicit) that were made during the design process. This can tell the designer areas where they were successful and what issues they need to address in future design work. For example, if users complain about a lack of privacy after a specific component was selected for the purpose of providing privacy, the designer may want to consider a different component in future work. This examination of an environment after construction and occupancy are complete is often referred to as a Post Occupancy Evaluation (POE).

The most comprehensive and useful knowledge can be obtained when users are systematically consulted before a design is implemented and after they have occupied the completed environment. The initial information helps to set priorities for design and then provides a baseline of information about experiences with comfort, privacy, and similar issues that can be compared to the subsequent experiences. Thus the success of various aspects of the design solution can be determined, and knowledge valuable for future facilities planning and design can be obtained.

Data gathering tools and techniques

Various types of information about how well the office environment is doing should be gathered. For example, observations can be made to see if space is being used efficiently, if workspace equipment is functioning well, or if designated use areas are being appropriately used. In addition, instrumentation can be used to monitor various office conditions such as air temperature and quality, or sound levels. Of primary importance to this section, however, is the measurement of users' evaluations and perceptions of their work environment and what experiences they have while in it. Systematically gathered information from those who directly experience the facilities on a day-to-day basis should offer a sound basis for decisions about modification or future design and planning. Indeed, information from people in the environment can identify problems with lighting, air quality, or acoustics as easily and perhaps more economically, than that gathered by using sophisticated instrumentation (Anderson and Weideman 1992).

Any of several techniques can help elicit information from users. Most common is the personal interview, or recorded "planned conversation." It is also common to distribute written surveys asking individuals to record their own (open-ended or structured responses).

What is critical, however, is that an appropriate, carefully developed tool be used for the circumstances. In most cases a written questionnaire with structured questions will be a good choice for obtaining information from users. This technique has a number of advantages. For example, all individuals are asked the same questions and have the same opportunity to respond. This facilitates comparison between individuals and groups of individuals. This approach is also generally the most economical. And, if the same questionnaire is used in a number of different environments, then opportunities for comparison of a set of environments can illuminate general design concerns of users.

While traditional written questionnaires have used paper and pencil media, questionnaires can be developed using electronic media. Such a survey could be distributed on a disk, LAN, or a separate workstation can be provided for gathering environmental responses. This could increase the speed with which information is collected from users and help prepare the data for analysis almost immediately. Data can go directly to a statistical analysis package, such as SPSS, or to a spreadsheet for analysis. Computer-based data collection may also elicit better responses from some individuals because the computer can control the sequence in which questions are asked, whereas individuals may skip about when using a traditional paper questionnaire. USACERL has pursued the computer-based questionnaire technique and is planning to publish its findings in FY95.

A Case Study

The HECSA case study (Appendix A) involved a two-story office building for an agency that dealt with the review of vouchers and disbursing of funds. The space was considered to have a number of problems (e.g., nature and amount of light, inefficient use of open office space, inadequate amount and types of storage, or poor acoustic quality). As part of the redesign process, it was decided to obtain information from the users to be used in the development of design solutions, and to be used later in an evaluation (Anderson et al. 1984).

Initial Assessment: Architectural Programming

Before developing design proposals, each employee of the HECSA office environment completed an open-ended questionnaire titled "To Meet Your Programming Needs," which showed a prototype workstation that was followed by three sections of questions. The first section dealt with equipment necessary for their job. Secondly, it asked for spatial requirements for storage. Finally, there were questions about the spatial layout, e.g., important proximities for doing the work. Information from this questionnaire was used to make changes in the office environment.

Evaluation Questionnaire

In examining the results of design decisions, designers and facilities managers rarely have the opportunity to conduct a true experiment in the sense that natural scientists do. Designers cannot use random assignment to deal with extreme variables, or control variables in the way they can be controlled in the laboratory. Still, designers can begin to approximate an experiment by undertaking a "quasi-experiment."

A quasi-experiment can take various forms; one of the more common is a time series study, in which information from the same people is gathered at more than one time. Then inferences are made about the relationship between any changes in their responses and corresponding changes they may have experienced over the time period. Information obtained this way can be considered more reliable and valid when several quasi-experiments suggest the same conclusion. This corroboration can help to make up for the lack of experimental control available in a laboratory setting. Thus, in the HECSA case study, a quasi-experimental approach was taken to examine information from the users about their office environment over time, before and after the changes to the setting were made.

Therefore, in addition to the information gathered for design development, another more structured questionnaire was distributed to all employees while they were still in the original environment (Before changes; Time1). This survey, titled "Evaluating Office Environments," asked for comprehensive information about their workspace, how they used it, and what kinds of experiences they associated with it. Sections included questions about their workstation activities, workstation environment (e.g., lighting, temperature, air quality, and acoustic conditions), specific workstation characteristics, work experiences, and ratings of performance and satisfaction levels.

Several months after employees had moved back into the redesigned workspaces, the office evaluation survey was again given to the employees (After changes; Time2). Thirty-one individuals responded to both surveys. An examination of the responses of these people provided an indication of where the remodeling was successful, as well as where problems remained.

The results are presented and discussed more thoroughly elsewhere. However, several examples will be presented here to illustrate responses that related to some of the issues discussed in various sections above, as well as to offer some suggestions about the usefulness of this general evaluation approach for designers and planners. First, two aspects of the workstation environment will be discussed briefly (temperature and lighting), then an evaluation of specific workplace characteristics will be presented. Finally, some information about work experiences will be presented. These will be discussed in relation to the nature of the changes that occurred.

Workstation Environment

Temperature Conditions

The frequency of certain temperature conditions at the workstation is shown in Figure 34. In contrast to expectations, the perceptions of temperature conditions worsened at Time 2. People felt that stable temperature conditions occurred less often in the new environment and were less satisfied with the workstation temperature at Time 2. This is a case where the remodel-

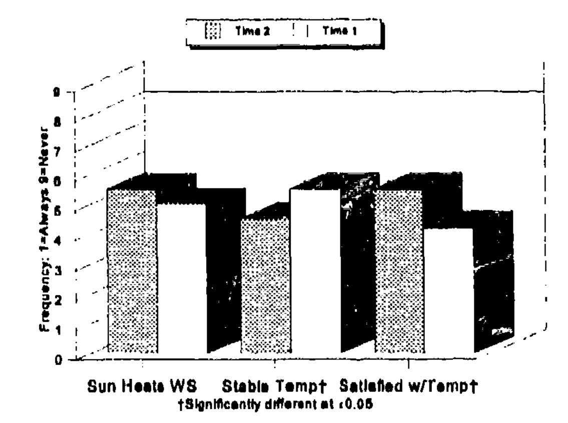


Figure 34. Workstation temperature conditions.

ing was not successful. Note that temperature issues were not among those originally defined as problems, and thus were not as effectively addressed. Occupants will probably remain distressed by the lack of thermal comfort until further changes are made in the system.

Lighting Conditions

One of the problems that was initially identified in the HECSA study was lighting. The design changes tried to address this issue. After changes had been made, people reported that they were more positive about light fixture positions, preferred incandescent lights, and showed a higher satisfaction with the lighting (Figure 35).

Workstation Characteristics

One of the primary expectations of the design solution was that people would be especially responsive to *specific* changes in the workstation setting. The HECSA design programming questionnaire asked specifically about storage issues, space layouts and amounts, and equipment needs. These were addressed in the remodeling. The evaluation questionnaire also asked about these issues, to see if improvements had occurred. Figure 36 contains the results of these evaluations of various specific workstation characteristics. Of the 14 items, eight showed

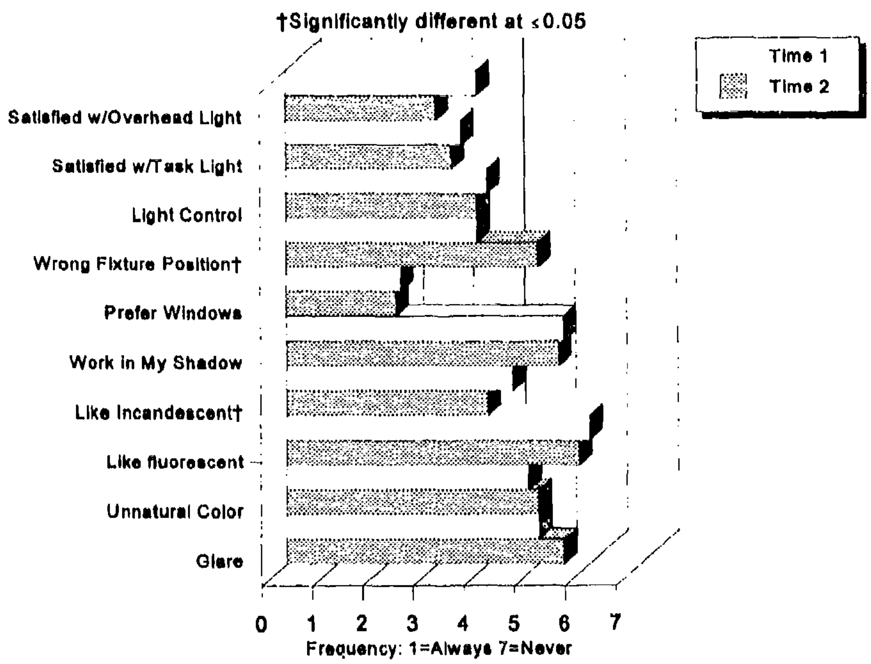


Figure 35. Workstation environment–lighting.

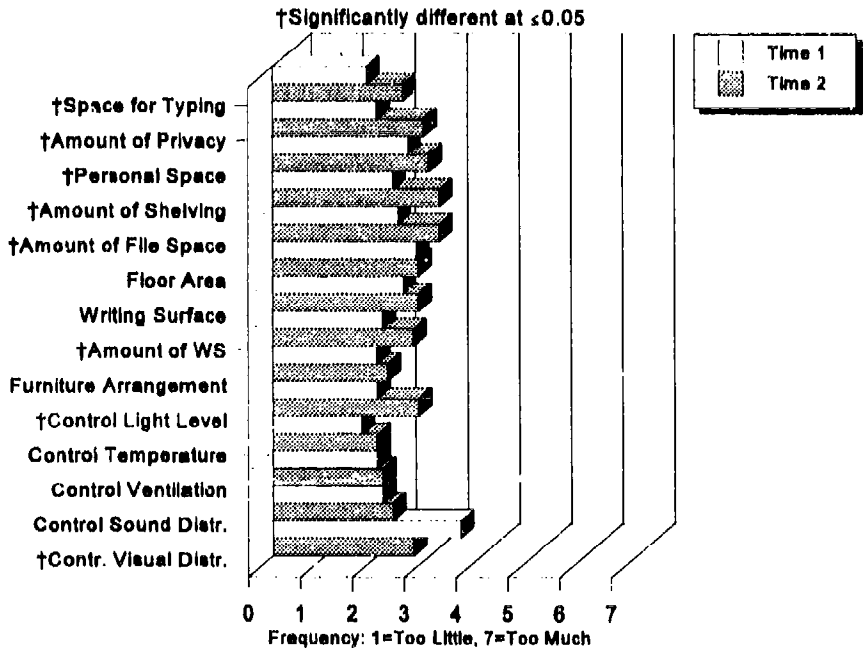


Figure 36. Evaluation of workstation characteristics.

significant perceptions of improvement at Time 2, as expected. Provisions for controlling visual distractions and light levels were perceived to be better. The amount of work surface, file space, space for computer materials, and shelving were improved. The amount of space for personal items, as well as the amount of privacy provided by the workspace were also felt to be better at Time 2. A ninth item, adequacy of the amount of writing surface space, approached statistical significance showing an improved perception at Time 2 also. Thus it is clear that workers perceived a change in specific characteristics of their workstation, and it was positive. Here is an example of where the remodeling was successful. The data confirms that the design provided a greater sense of space, even when the amount of actual space was not increased overall but rather decreased. Furthermore, this is a very clear demonstration that obtaining information from users before changes are made (e.g., via the programming questionnaire) and using that information in the design development can result in positive work outcomes.

Work Experience Outcomes

An unexpected finding in this quasi-experiment demonstrated the importance of evaluating work environments after changes have been made or when people occupy new spaces. Figures 37 and 38 display the differences in a number of

outcomes reported from working in the original and remodeled office environments. Eleven are physical in nature. And three of the eleven show a difference in which they are found to be worse: headaches, nausea, and wrist/arm soreness. Two other physical conditions approached statistical significance; they indicated an increase in respiratory problems and throat irritation after the changes.

These were undesirable changes that may have several possible explanations. First, there may have been some outside event that occurred just before the "after changes" evaluation. For example, an outbreak of flu could account for some of these outcomes. Another possible reason has to do with changes in the work environment itself. An issue discussed in previous sections is the possibility of at least a temporary "sick building syndrome." Physical illnesses can result from ventilation and air quality characteristics. It is important to note that this evaluation occurred only months after the remodeled space was occupied. Furthermore, it occurred in the fall of the year when heating and ventilation systems might be used more. In addition, chemicals in new furniture, carpeting, or paint could be still a factor in producing indoor air pollution. This factor, coupled with the seasonal change, could produce a sick building effect.

Two points must be made; first, without an evaluation of the new environment,

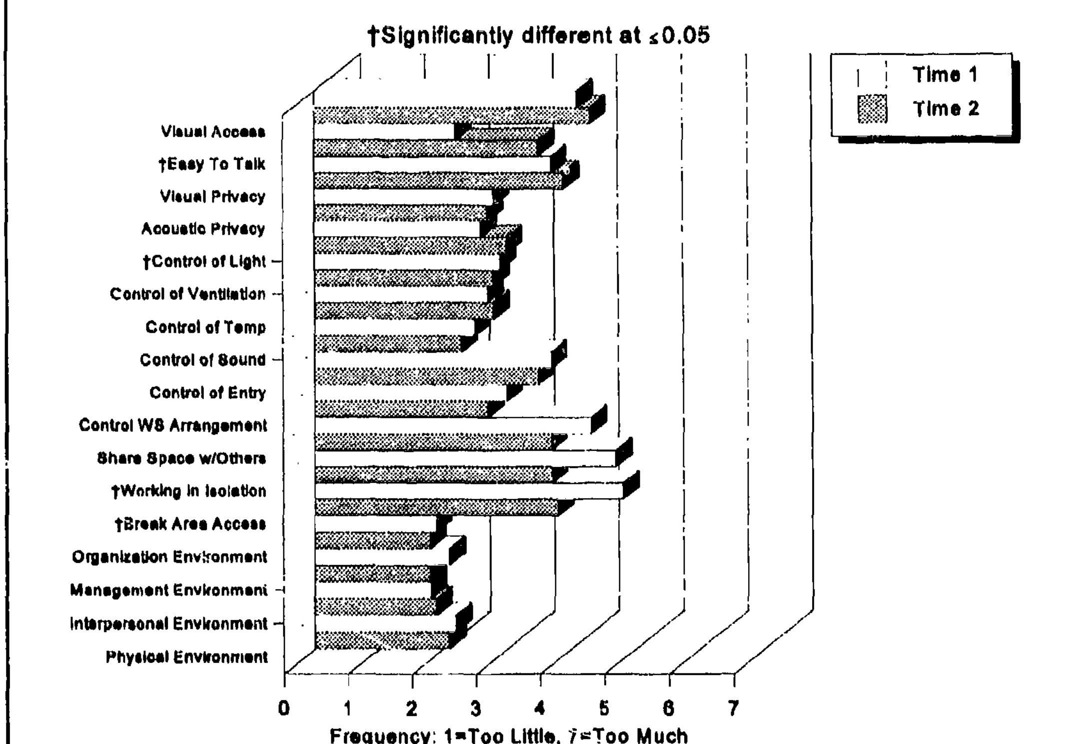


Figure 37. Importance of workstation characteristics.

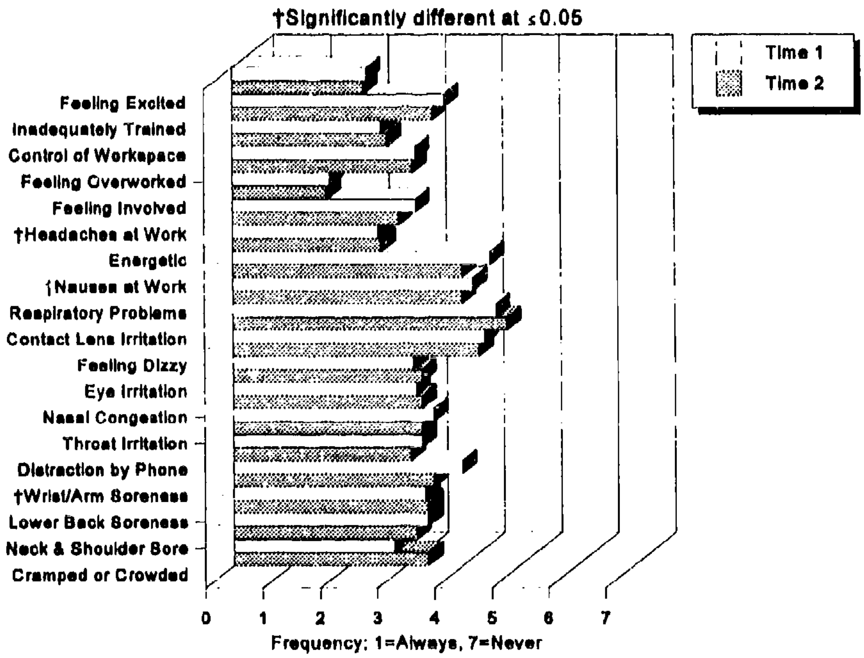


Figure 38. Importance of work experiences.

this potentially disruptive (in terms of real costs of health, time and dollars) would not have been recognized. Second, considering the circumstances of the newness of the facilities, it would be important to have another evaluation. If the problems were temporary, these experiences should have diminished with time. If they persist, then steps should be taken to reduce their effects.

In summary, the HECSA case study has offered valuable information about what information is important to obtain from users, when it should be gathered within the design and implementation process, and how it can be obtained. The results have shown where successes have occurred and illustrated a potential problem. The methods of addressing a number of relevant design problems have been discussed in previous sections. And the methods of gathering information from the users of the facility can be used again, to test for improved conditions.

6 Summary

Tools Are Available

The tools for obtaining information about how users perceive their work environment are easily available. USACERL has an evaluation questionnaire ("Evaluating Office Environments") that has been tested in over a dozen different office environments. A baseline of data has been developed so comparison can easily occur. The original paper and pencil questionnaire process is being converted to a computer-based questionnaire to facilitate obtaining information from users and speed the process of data analysis and presentation of implications for design.

The Importance of Interior Design

While one may intuitively feel that good interior design can improve the quality of the work environment and work performance, it is essential to empirically test the success of design decisions. The HECSA experiment mentioned briefly above (and discussed in more detail in the Appendix to this report) is only one of a number of studies that show the value of appropriate interior design. Furthermore, the research must go beyond basic descriptive information to be of full use. When dollars and resources are limited, any information that can suggest priorities for changes is important and useful. The research on the value of good interior design (e.g., as it relates to type of space, or levels of privacy) has clearly shown its importance in terms of job satisfaction and enhanced performance.

Future Design Information

Two general types of empirical information can be useful for future design. First, there is the issue of what aspects of the interior design are most important for job satisfaction and performance outcomes. That can be determined by research that examines information from a variety of sites. The second, more immediately useful, type of information for interior designers has to do with the evaluation of a specific space. For example, if privacy issues were found to be strongly related to performance (in the first type discussed above), then design issues related to

privacy could be assessed for any particular work setting; where it is shown to be deficient, then the interior designer would be able to provide specific solutions based upon information about the deficiencies.

In summary, research has begun to clearly demonstrate the importance and value of interior design in the work environment. What remains is to extend the existing base of knowledge, apply it to real situations, and continue to monitor the extent and nature of its success over time.

Metric conversion table

1 in.	=	25.4 mm
1 ft	=	0.305 m
1 sq ft	=	0.093 m^2
°F	=	(°C × 1.8) + 32
1 acre	=	0.405 hectare

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Appendix: The HECSA Interior Design Case Study

The data for this case study were obtained from the individuals working at a Finance and Accounting Support Office at the Humphreys Engineer Center Support Activity (HECSA), Fort Belvoir, VA. Plans for expansion in this office provided an opportunity to obtain and use information from the staff in the modification of the site. Initial study of the site began in 1991 with conversations and site visits, which were followed by the administration of a survey—To Meet Your Programming Needs—intended to obtain specific workstation information from the staff. Based on this set of information, decisions about the nature of the changes were made. Before construction began, all office employees were asked to complete a more extensive structured questionnaire (Time 1)—Evaluating Office Environments—containing items that measured their perception of the specific characteristics of the work environment, outcomes of working in that environment and demographic characteristics of the respondent. The actual changes in the office environment were made in the spring and summer of 1992. Following these changes, all employees of HECSA were again asked to complete the same structured questionnaire (Time 2). Thirty-three individuals were present at both time one and time two. Analysis showed that these office workers perceived many aspects of their work environment differently after the renovation. Many different characteristics such as layouts of before and after the renovation, lighting, temperature, workstation characteristics and air quality were perceived differently. This case study discusses the specific findings and their implications for the design and management of other office environments.

Hypothesis

It was hypothesized that changes in the office environment would be seen in a positive way and that these perceptions would be related to positive changes in the outcomes of the office environment.

Approach

This case study was done as a quasi-experiment. Specific characteristics of the work environment were manipulated by redesigning a number of work areas. Workers were asked to evaluate their workspace before changes occurred (Time 1) and then after they were moved into renovated work areas (Time 2).

The employees were not randomly assigned to new workstations and it was not possible to control all other potentially intervening variables, thus this research could not be a "true experiment." However, quasi-experimental research designs also serve for examining the results of interventions in field settings.

The data were obtained through use of a previously developed, structured questionnaire (Anderson and Weidemann, 1992). This questionnaire had been tested on 190 individuals in 12 different buildings and was found to be both reliable and valid. The questionnaire was first administered to all employees of the Finance and Accounting Support Office (HECSA) about 8 months before construction began (64 of 81 employees responded). The questionnaire was given again 2 months after the renovations were completed (October 1992). The questionnaire was distributed to all of the employees and 54 responded.

Each time, the questionnaire contained a place for the respondents name. This allowed matching of individual responses that had been there before and after the renovation. As a result this study demonstrates that changes made to the physical characteristics of a work environment are, indeed, perceived by the individuals working in that environment and impact their productivity.

Method

This project involved a two-story office building consisting of three parts. As HECSA's finance and accounting requirements expanded, existing floor plans were changed according to immediate needs without design assistance. The office was furnished with individual desks, chairs, and tables, and some individuals were in partitioned office space, while others were in open rooms with several individuals. The existing floor plans (Figure A1) and investigation by designers (surveys and site visits) showed the following deficiencies:

1. Insufficient natural light penetrating the open office space
2. Inefficient and disorganized use of open office space

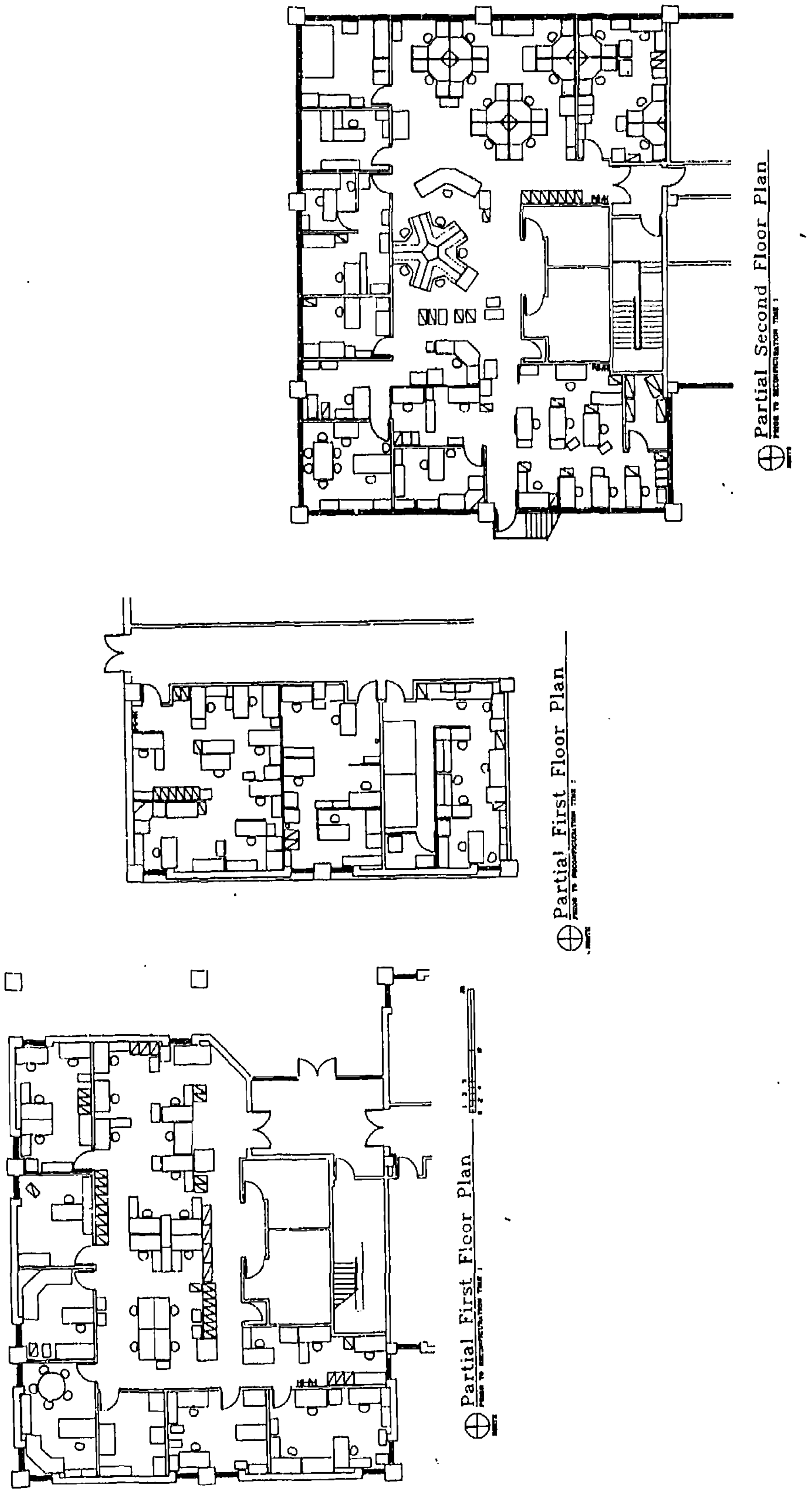

Figure A1. Existing floor plans for HECSA office space.

3. Lack of organizational definition between various divisions
4. Insufficient lineal feet of worksurface area
5. Potential code violations and hazardous personnel circulation requirements due to poor wire management and file placement
6. Inadequate amounts of file storage
7. Inadequate lighting
8. Inadequate acoustic quality.

Consequently, worker productivity was adversely affected, and a decision was made to reconfigure the facility.

Subjects

The subjects of this research were the individuals working in the F&A offices just prior to the office renovation and those working in the F&A offices 2 months after completion of the renovation. Of the 100 employees of F&A, only 31 respondents were present at both Time 1 and Time 2. After several presentations, a solution was achieved using systems furniture. The design team addressed the above issues and the benefits gained from the reconfiguration (Figure A2) include:

1. Increasing worksurface area while decreasing amount of occupied space

2. Elimination of hazardous circulation paths by
   - Using electrified panels for wire management
   - Providing overhead storage bins and additional filing components
   - Providing corridor widths that meet or exceed code requirements

3. Providing acoustic panels throughout to reduce noise levels

4. Improving lighting by
   - Providing task lights to meet individual needs
   - Relocating fully enclosed offices to center "core" allowing natural light to penetrate the open office spaces

5. Providing fully adjustable components for ergonomic control

6. Creating additional spaces:
   - New conference rooms on first and second floor
   - Additional workstations

7. Creating two to three times the amount of storage capacity.

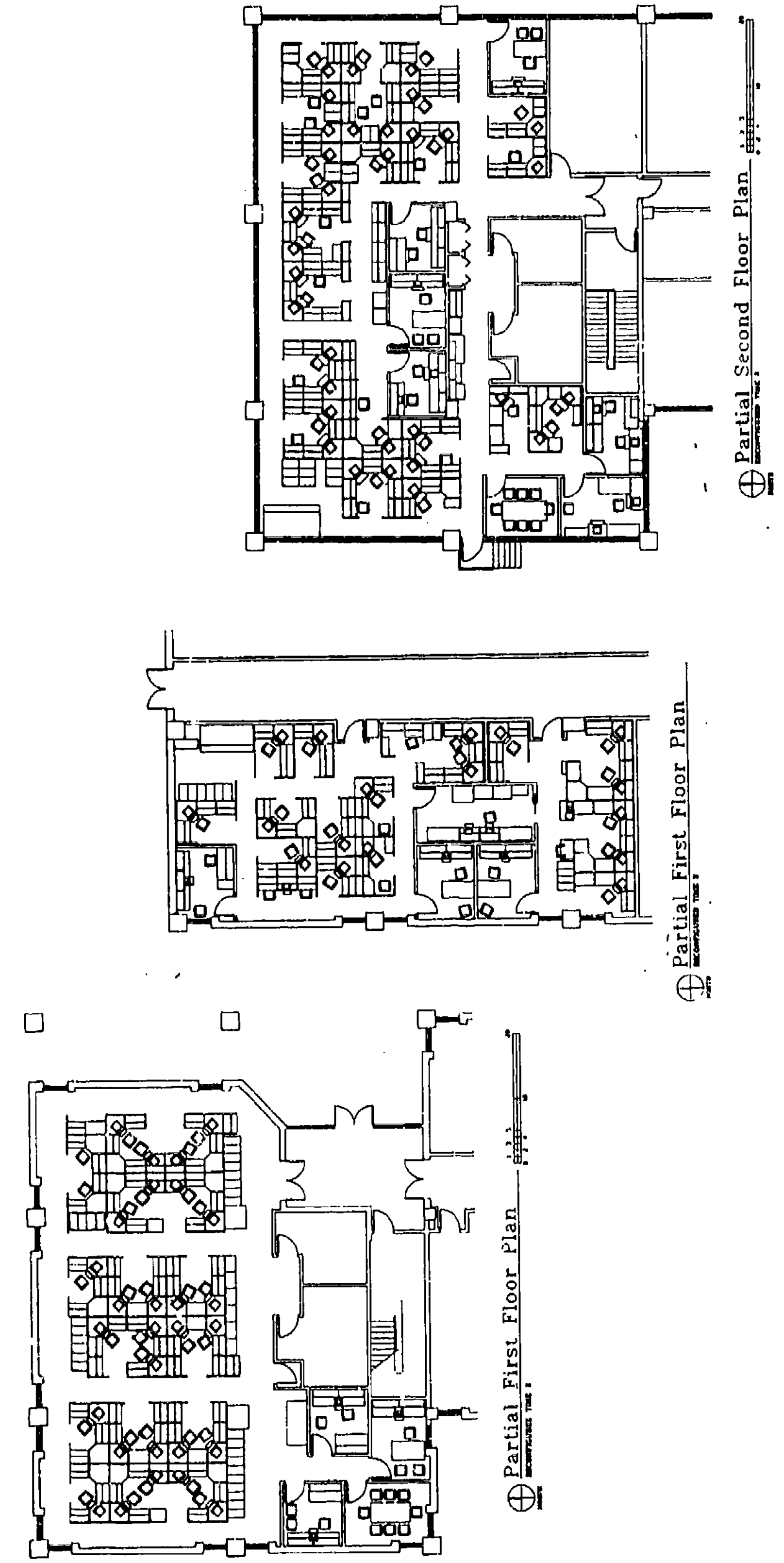

Figure A2. Reconfigured floor plans for HECSA office space.

Questionnaire

The questionnaire that was used measured a worker's perception of a number of characteristics of the work environment, workstation layouts before and after the renovation, lighting, temperature, workstation characteristics, and air quality, as well as workers' experience with physical and psychological outcomes of work.

Comparison of Time 1 and Time 2

The following analyses illustrate some of the average responses of 33 employees to an initial work environment of traditional office furniture (Time 1) to the response of those same 33 employees to a renovated environment with systems furniture (Time 2). At the time of this writing the U. S. Army Construction Engineering Research Laboratories (USACERL) was in the process of publishing an extensive technical report on this case study.

Lighting Conditions at the Workstation

Some items in Figure A3 represent preferences for incandescent, florescent, and natural light. Although some designers have argued for windowless office environments, the comparison of these three items suggests that windowless designs should not generally be pursued. At Time 2, the t-test indicates that people were more favorable about incandescent lighting.

Although there were no statistically significant differences from Time 1 to Time 2 for "having sufficient control of lighting" and being "satisfied with the task lighting," the direction of responses were in the hypothesized direction, i.e., responses were more positive after the changes. Comments written in response to the question "What are the good things about the lighting at your workstation?" also indicated the importance of control of lighting, e.g., "I have control of undershelf lights" and "ability to control amount of light."

Although Figure A3 does not show a statistically significant difference in glare between Time 1 and Time 2, the comments to the open ended question "What are the bad things about the lighting at your workstation?" suggest that glare is an important problem for some people. Among the comments made by 32 respondents, the most frequent comment concerned glare on the PC screen, e.g., "overhead lights put glare on the screen" and "overhead lights are behind me at my computer."

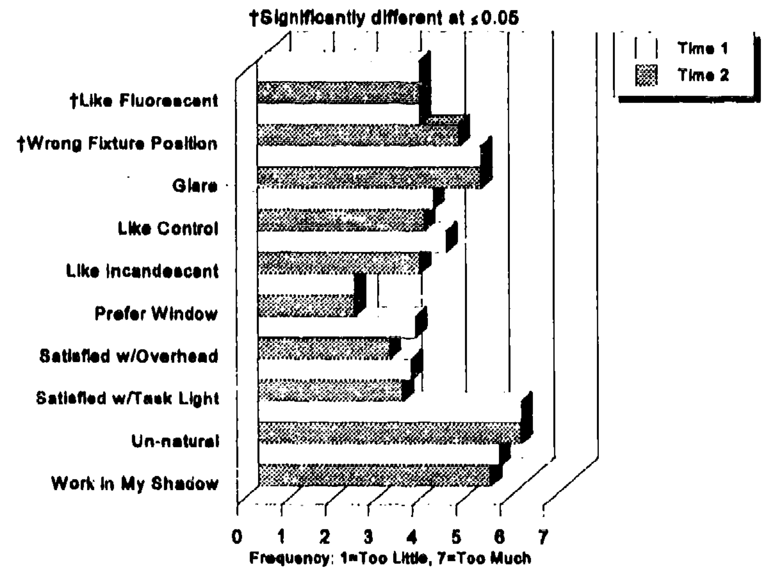

Figure A3. Workstation environment—lighting preferences.

The open-ended responses also showed a concern for the pattern of lighting in the office with comments like "not evenly distributed" and "not evenly lit." This may indicate that at least some of the occupants of this office are using a brightly lit and evenly lit ideal as their model of comparison. In fact, this was the model of lighting designs in past decades. Today's designs tend to be more energy conscientious, directional, and user-controlled. It may take time for workers to lose this expectation for the way their work environment is lit.

Adequacy of light levels for various tasks are shown in Figure A4. Although there were no significant differences at the 0.05 level, there were, again, responses that approached significance (levels from 0.06 to 0.11) for three items. At Time 2, lighting conditions for reading the computer screen, for writing, and for conversing with others were more positive (closer to "just right" on the scales), a pattern that suggests the lighting changes were generally positive and effective. In fact, the majority (10 of 28 responding) of open-ended comments describing "good things about the lighting" focused on the adequacy of light levels with comments such as "well lit" and "sufficient lighting for all purposes." Only four individuals indicated that the workstations were "too dim" or "too dark."

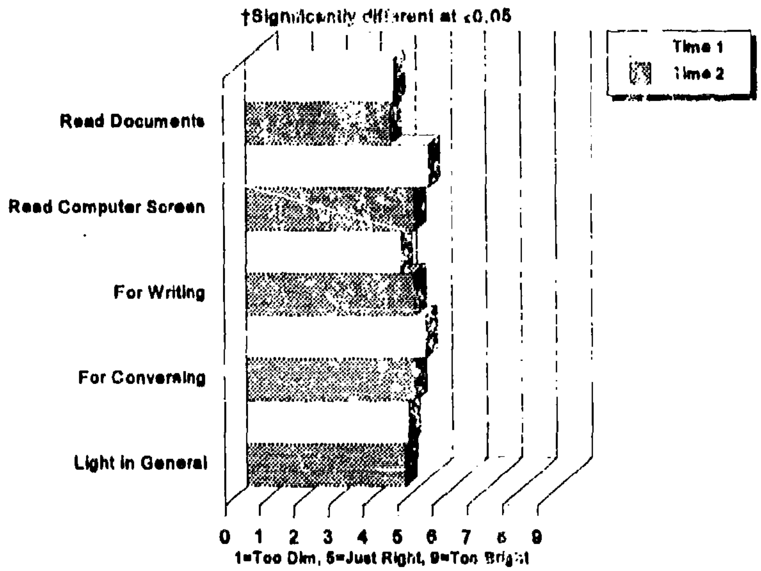

Figure A4. Workstation environment—lighting conditions.

Temperature Conditions at the Workstation

Figure A5 shows the frequency with which certain temperature conditions at the workstation occurred. In contrast to expectations, temperature conditions worsened at Time 2. People were less satisfied with the workstation temperature, and felt that stable temperature conditions occurred less often. This dissatisfaction with the thermal conditions of the environment is further highlighted in the open-ended comments. When asked at Time 2, "What are the good things about the temperature conditions at your workstation?" 57 percent responded with negative comments, e.g., "Nothing," "There aren't any," and "If I ever want to experience the arctic I only have to come to work."

The problem of temperature stability which is indicated in Figure A5 is also emphasized in the open-ended responses. When asked "What are the bad things about temperature conditions in your workstation?" 35 percent made comments indicating that temperature conditions were generally not stable, e.g., "too hot in the afternoon," "you either freeze or sweat," and "unpredictable temperature."

In spite of these negative evaluations, Figure A6 shows that summer workstation temperatures have shown a tendency to improve with the average response being "just right." The difference between Time 1 and Time 2 responses to this item approached statistical significance. There were no perceptual differences for the

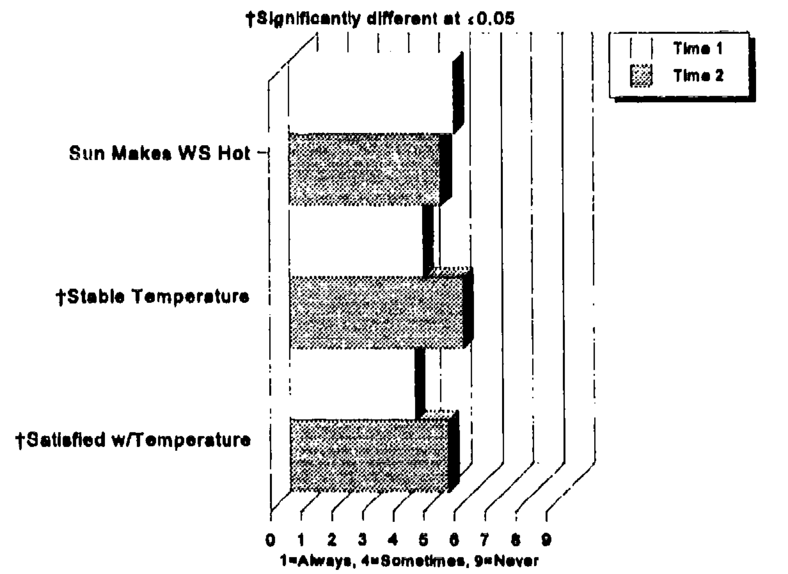

Figure A5. Workstation environment—general temperature conditions.

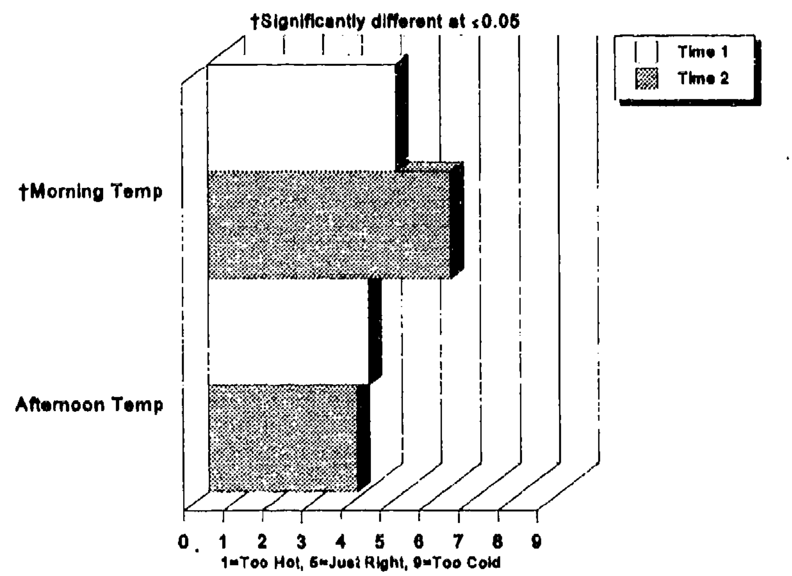

Figure A6. Workstation environment—daily temperature conditions.

Figure A7 shows that perceived morning workstation temperatures were significantly worse after the change, in that they were judged to be too cool. Afternoon temperatures were still felt to be somewhat warmer than comfortable.

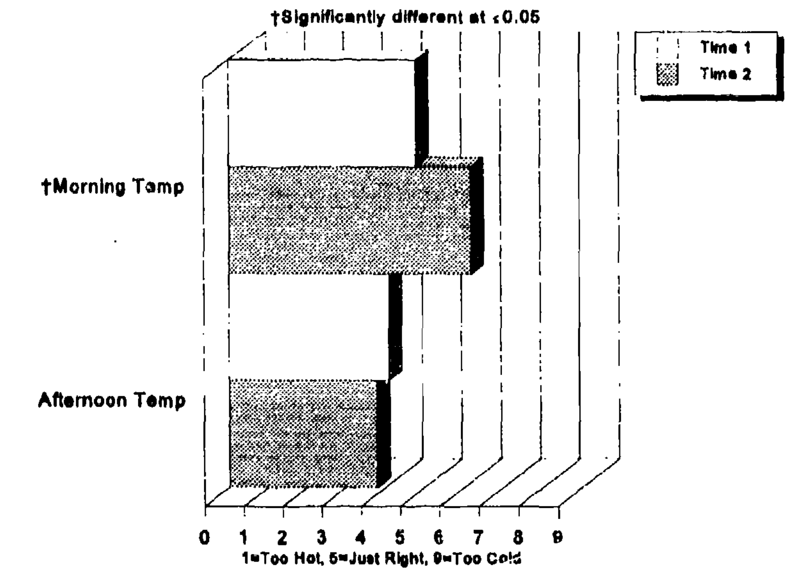

Figure A7. Workstation environment—daily temperature conditions.

Again, the open-ended comments reinforce each of these ideas: the temperature is too cool in the morning, too hot in the afternoon, and not stable during the day.

Workstation Air Quality

How frequently a person experiences the air quality conditions at their workstation is shown in Figure A8, as well as an overall evaluation of air quality. In general, the figure shows that the average perception of unpleasant odors and tobacco smoke did not vary were between Time 1 or Time 2. It also shows that these two problems were infrequently experienced. In fact, about 40 per cent of the respondents at time 2 said they were not aware of unpleasant odors and over 75 per cent were not aware of smoke.

There was significantly less dust in the air after remodeling (Time 2). However, there was no change in satisfaction with the air quality at their workstation. It remained at an intermediate level.

Workstation Characteristics

One of the primary expectations of this research was that people would be especially responsive to specific changes in the workstation setting. Figure A9 contains evaluations of various specific workstation characteristics.

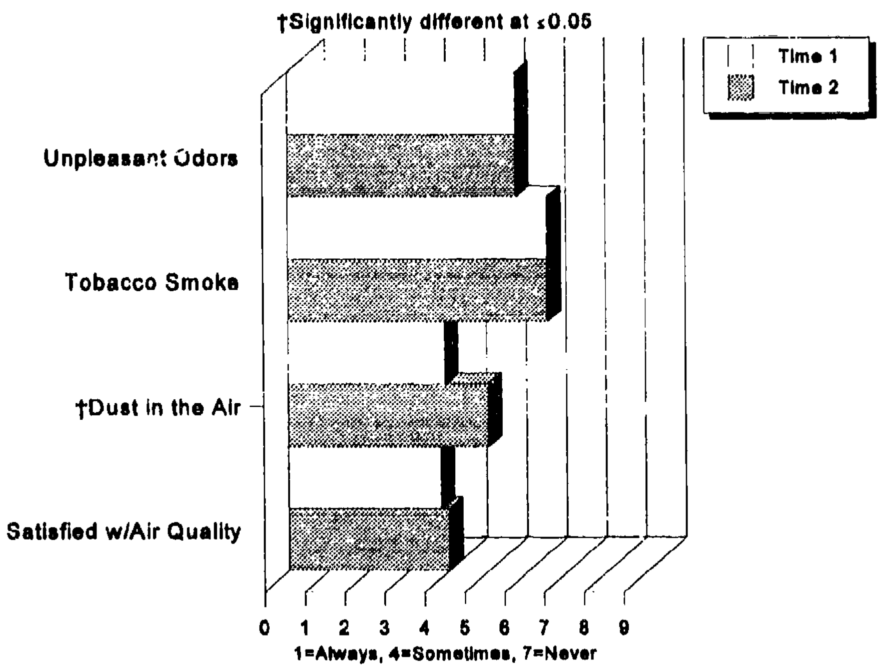

Figure A8. Workstation air quality.

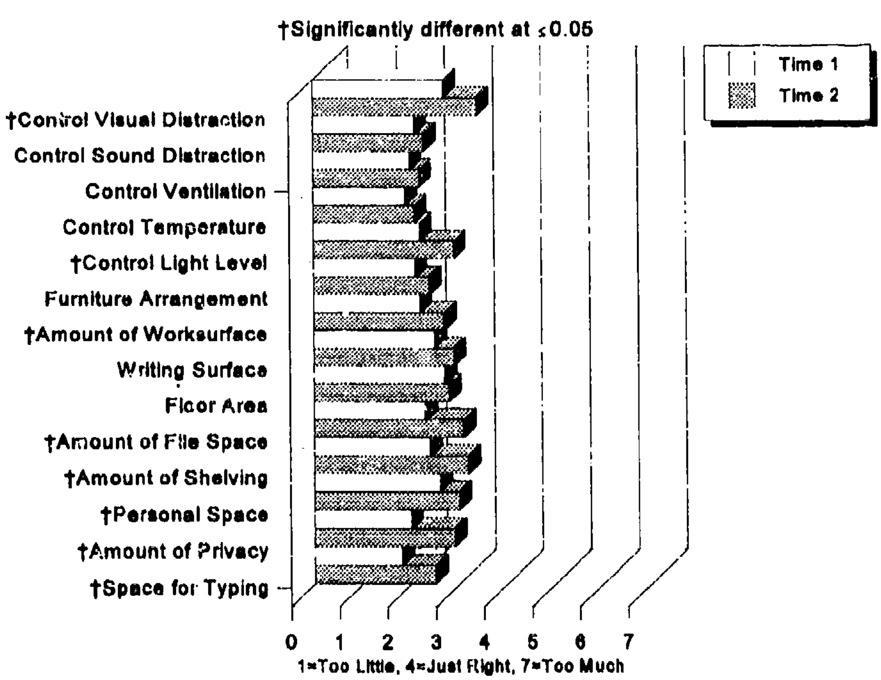

Figure A9. Workstation characteristics.

Of the 14 items, eight showed significant perceptions of improvement at Time 2, as expected. Provisions for controlling visual distractions and light levels were seen to be better. The amount of work surface, file space, space for computer materials, and shelving were improved. And the amount of space for personal items, as well as the amount of privacy provided by the workspace were also felt to be better at Time 2. A ninth item, adequacy of the amount of writing surface space, approached significance showing an improved perception at Time 2 also. Workers clearly perceived a positive change in specific characteristics of their workstations.

Satisfaction With The Workstation

Figure A10 presents the variables which were significantly correlated (p equal to or less than 0.05) with "Satisfaction With The Workstation" (V149). The variables describe five general categories of workstation conditions. There are three which deal with the issue of temperature and ventilation, five which address acoustic conditions, one which deals with lighting, and eleven which focus on amounts and types of workstation conditions that primarily deal with amount of various spaces and privacy aspects. With one exception, all of these relationships indicate that the more adequately the conditions are fulfilled, the more satisfied respondents were with their workstation. The one exception was that of variable 68, an item that asks if workstation size is a problem. There was a negative relationship, which apparently suggests that they would be more satisfied with their workstation when size of the space was a problem. This is in contrast to all other significant relationships, which may be spurious because the sample size is small.

Two other items suggest why it is important that workstation conditions be considered to be adequate, and supportive of the activities that must occur in them. To the extent that people felt satisfied with their workstation, they also felt that they were able to adequately take responsibilities, and they were able to meet deadlines at an acceptable rate. These variables could be considered as intermediate "outcomes" of a suitable work situation. That they are found to be related to satisfaction of the workstation itself serves to emphasize the complex relationships between physical characteristics of the work setting and more general outcomes such as satisfaction.

Conclusion

It was hypothesized that changes in the office environment would be seen as beneficial and that these perceptions would be related to positive changes in the

outcomes of the office environment. In this case study, the hypothesis was tested and the results indicate it can be accepted as a valid statement. On average, most of the office workers at HECSA found their new work environment after the renovation (Time 2) to be better than before the renovation (Time 1) in a variety of categories. They indicated that they not only had more of their functional needs met, but also their level of satisfaction was increased. This higher level of satisfaction equates to a potential increase in productivity. However, there are some satisfaction aspects and productivity values that were not measured and are therefore not numerically documented, *e.g.*, does the new work environment specifically increase the output—e.g., "more widgets per hour." It is important to note that measuring productivity in a more controlled setting versus this quasi-experiment, can provide better numeric proof of the success of any design. Based on that evidence, this survey can provide more informed design decisions that will better satisfy the functional and preferred needs of the office users.

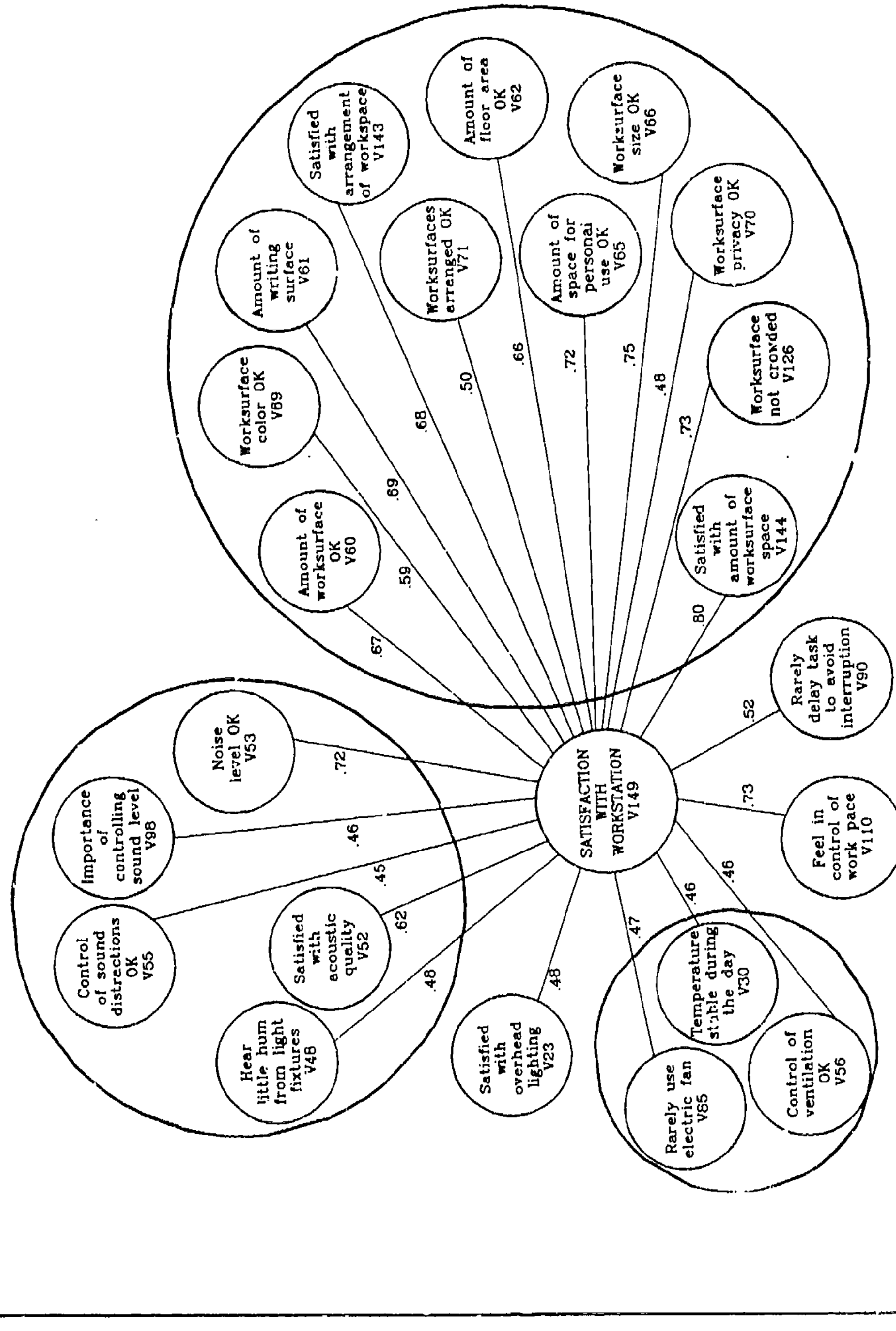

Figure A10. Correlations associated with satisfaction with workstation—Time 2 ($p \leq 0.05$).

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